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20 October 1964

SUBJECT: Clearance of Report

TO: Commanding Officer
      Defense Documentation Center for Scientific and
        Technical Information
      Cameron Station
      Alexandria, Virginia

    1. On 17 March 1964 there was forwarded by this office, for release to the Office of Technical Services, Department of Commerce, Contract Report No. 2-67, July 1963, by Nathan M. Newmark, entitled: "Design of Openings for Buried Shelters".

    2. Errata sheets are attached for this report.

    FOR THE CHIEF OF ENGINEERS:

1 Incl
  Errata Sheet (1 cy)

FRANK MILNER
Colonel, Corps of Engineers
Chief, Technical Liaison Office

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Revised Charts 6.03 and 6.04 are attached to replace the charts
contained in the report. The curves in the original charts were based
on elementary considerations that yield results now found to be non-
conservative under some circumstances. The revised curves are obtained
with the use of a somewhat more sophisticated analysis.

The revised curves are calculated with the use of information
available in a report by Spielberg and Duneer. In particular, they
are based upon dose rate curves for neutrons incident at various angles
upon material designated as "R_{10}," which is representative of ordinary
concrete and generally of most earth with a moisture content of about
10% by weight. (They are conservative if the water content is higher,
but err in the non-conservative direction if the water content is lower.)
The data from Spielberg and Duneer must be weighted by the proportion of
neutrons which are incident on the barrier at various angles to the
normal. Since the data in Spielberg and Duneer are given for angles of
incidence of $0°$, $20°$, $45°$, and $75°$, some assumptions must be made as to
the assignment of the percentage of incident neutrons to each of these
directional groups, for the two cases of "normal" and "grazing" line of
sight. The discussion in Section 5.04 gives some information relative
to this assignment, but judgment must be employed also. The assumed
angular distributions, applicable to both 2.5 MeV and 14 MeV neutrons,
are as follows:

Angle	Normal line of sight	Grazing line of sight.
$0°$	15%	5%
$20°$	40%	10%
$45°$	30%	35%
$75°$	15%	50%

The curves are normalized to an incident flux of 1 neutron/cm^2 sec.
by using as a reference the dose in rads for an integrated flux of one

---

D. Spielberg and A. Duneer, "Dose Attenuation by Soils and Concrete for
Broad, Parallel-Beam Neutron Sources," AEC Document AN-108. Associated
Nucleonics, Inc. (May 1, 1958).

neutron/cm.^{2}, as given in Table 2.2 of Spielberg and Duneer. This should give conservative results, since the flux incident on the slab is not the same as the total flux just above the slab: the latter includes also the dose rate reflected from the slab. This conservatism is desirable because of uncertainties in the accuracy of Spielberg and Duneer's calculations.

It is to be noted that the resulting curves are not highly dependent upon the direction of the line of sight.

The reader should be advised that the illustrative example given in Chapter 9 of the basic report uses the data from the original curves in Charts 6.03 and 6.04, and are incorrect to that extent. The methods employed, however, are unchanged.

NOTE.: Curves Applicable to Earth of Average Dampness and Concrete Barriers
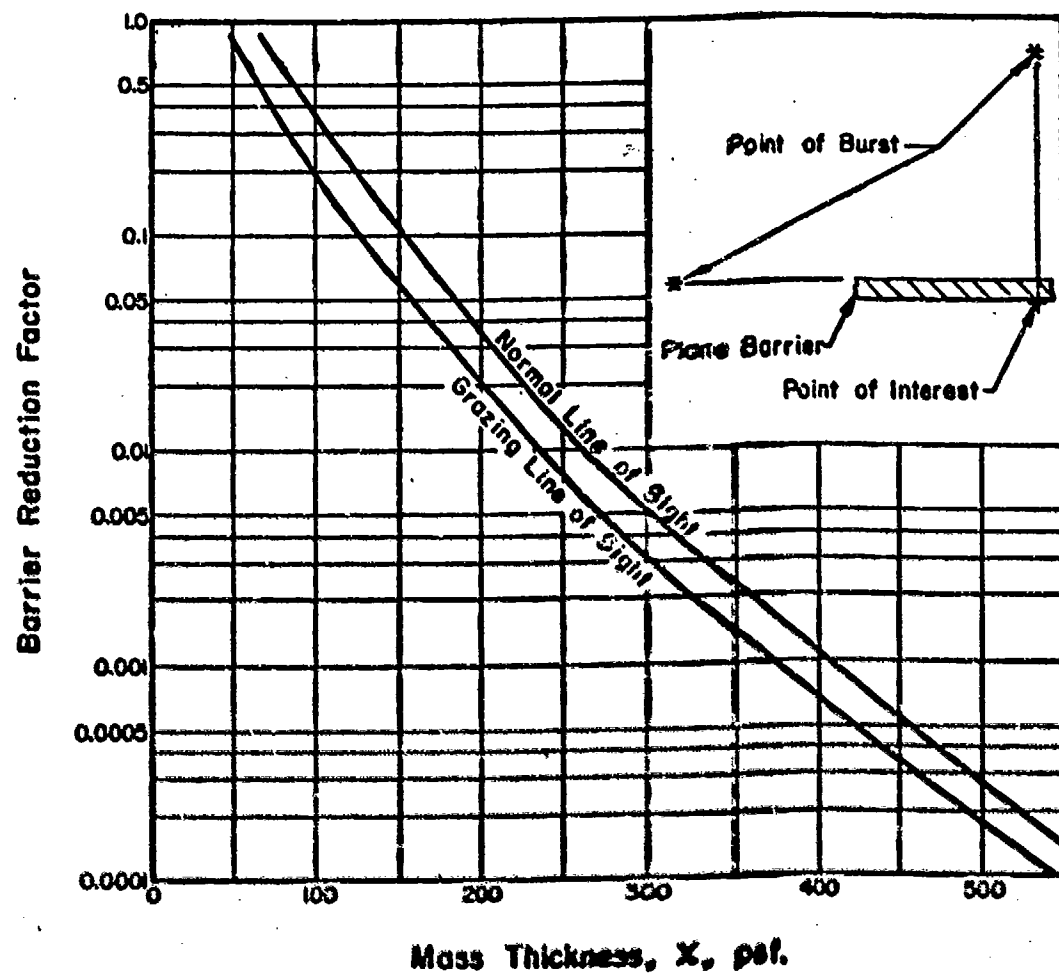
CHART 6.03 BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR

2.5 MEV NEUTRONS

(Revised June 1964)

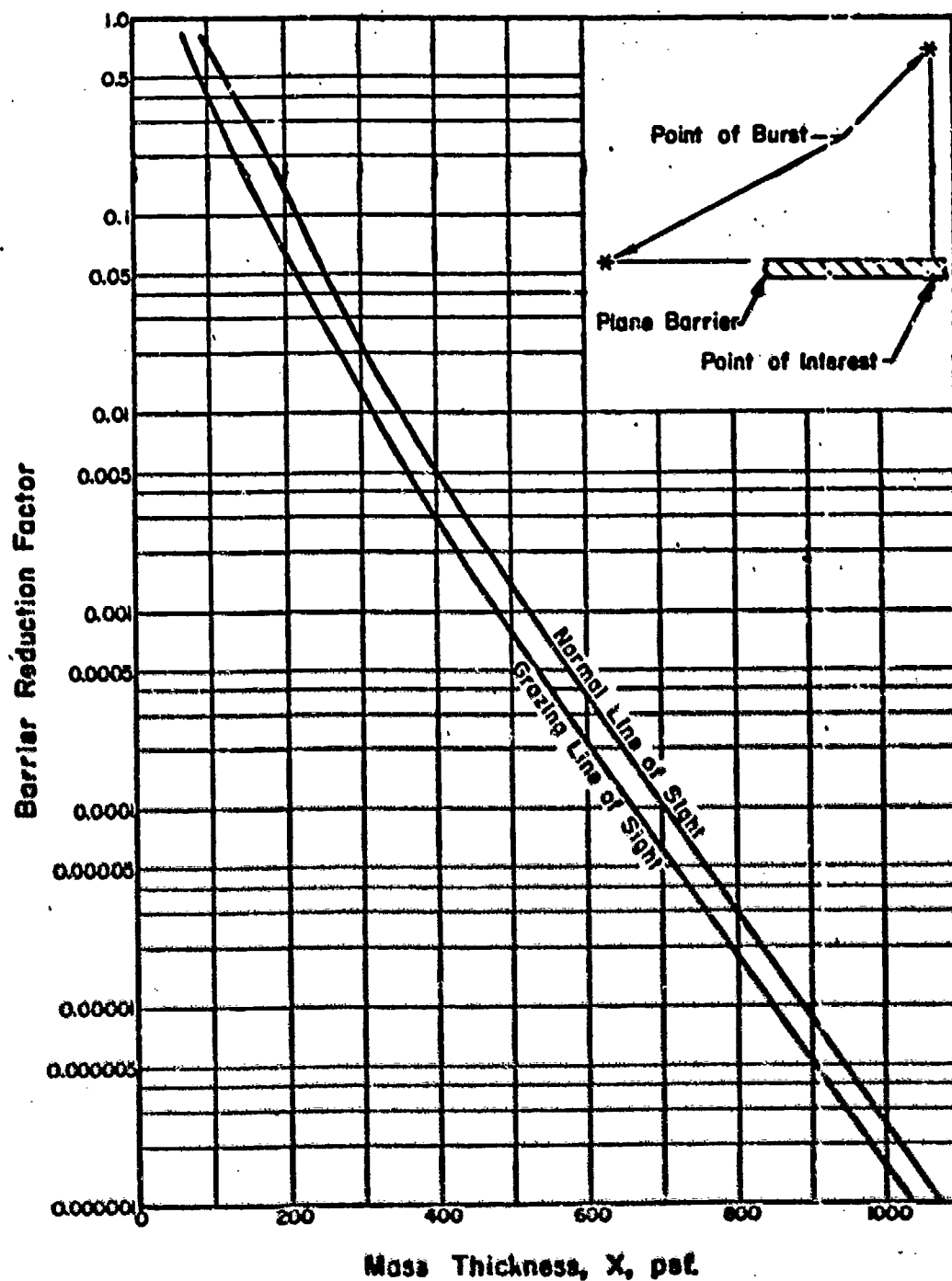NOTE: Curves Applicable to Earth of Average
Dampness and Concrete Barriers.

CHART 6.04 BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR
14 MEV NEUTRONS

(Revised June 1964)

(5) 638800

NP-13459

DESIGN OF OPENINGS FOR BURIED SHELTERS

by

Nathan M. Newmark.

DDC

JAN 22 1964

TION A

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U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

research may provide a better basis for the selection of recommended values of human tolerances.

It has been assumed that those who will use this report are familiar with the following publications; "Effect of Nuclear Weapons", U. S. Government Printing Office; "Design of Structures to Resist Nuclear Weapons", ASCE Manual No. 42 and "Design and Review of Structures for Protection from Fallout Gamma Radiation, 1 Oct. 1961".

CONTENTS OF REPORT

In order to establish the general framework within which the project proceeded and to state the general factors affecting the approach, the solutions, and the limitations, Chapter 1, "Basic Design Considerations", discusses the standards of protection, the tolerances of humans in a shelter, the influence of local ordinances and/or codes, and the role of shelter management and operational procedures.

The objective of Chapter 2, "Shelter Entrance Systems", is to state the specific assumptions made in relation to the shelter entrance system. Included herein are discussions of the elements of entrance systems, the influence of depth of structure relative to the outside grade, the dependence or ingress traffic rates, and the operational concept of the door closure as it affects the design.

The objective of Chapter 3, "Dimensions and Geometry of Entrance Systems", is to establish a range of recommended dimensions of the system elements and to catalog them in a convenient format. A number of alternate geometries are presented.

In Chapter 4, "Ventilation Systems", the objective is to state and discuss the specific assumptions made in relation to the ventilating system. Included are discussions of the elements of the ventilation system, intake and exhaust structures, the effect of the location of emergency power supply, and blast valves.

Chapter 5, "Effects Input Data", presents the weapons effects parameters pertinent to the problem of the design of entrance and ventilation structures appurtenant to a 50-psi shelter.

In Chapter 6, "Radiation Shielding Design Parameters", and Chapter 7, "Blast Resistant Design Parameters", are presented the

FOREWORD

The work undertaken on this contract pertains primarily to the exploration of low-cost protection of shelter openings against blast and associated thermal and nuclear radiation, emphasizing protection for 50 psi for all weapon yields and the associated effects for 1 MT. The entrance structures considered are of a general nature appropriate to buried structures in general rather than to a particular structure. The end result is an example solution to an assumed entrance situation.

It will be noted throughout the report that there is considerable discussion of the interaction between the shelter entrance and various other shelter systems. It is virtually impossible to design a shelter entrance without considering the influence of the shelter proper.

The protection of shelter openings has been restricted to their architectural configurations and the structural and mechanical elements between the ground surface and the enclosing structural shell of buried shelters. These elements include the transition element at the surface, the depth element to permit movement from one depth to another, the corridor element (to serve as a passageway and to reduce the blast and radiation intensity), optional interlock element, the blast exclusion element (door) and the transition element between the entrance structure and the envelope of the shelter proper. These elements are considered separately in order that various conditions may be satisfied, such as, ground terrain conditions; the location of the shelter, i.e., buried, semi-buried, or surface covered; side or end access to the shelter proper; shelter shape configuration; etc.

In order to accomplish the objective of this project, it has been necessary to establish or to assume certain design criteria and standards. While some of these, such as flow rate of personnel into shelter are substantiated by previous tests, it is emphasized that others such as human radiation tolerances are not to be considered as recommended or prescribed allowables. The values used in this report were assumed in order to present a quantitative example. Subsequent

design criteria, the resistance expressions and the charts developed to design various elements of an entrance system. The design charts cover a range of conditions so that one can select elements of a particular strength or capacity to synthesize them into a design to meet given conditions.

Chapter 8, "Design Procedure", is based on the material in the preceding chapters. It includes a general design procedure that is followed in Chapter 9.

An example design solution utilizing the charts and procedures developed in the preceding chapters is presented in Chapter 9, "Illustrative Design Example".

ACKNOWLEDGMENT

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CHAPTER 1.   BASIC DESIGN CONSIDERATIONS

1.01   INTRODUCTION

As in all other engineering problems, the engineer involved in the design of protective construction wants to achieve a balanced design. In its simplest expression balanced design implies a "one-hoss shay" concept; that is, the structure performs each of its design functions equally well and there is no weak link. In protective construction, this would imply that the occupants of the structure are protected to an equal degree against all of the effects of nuclear weapons, i.e., that the occupants are not subjected to lethal doses of radiation in a structure which is adequate to protect them from blast and vice versa.

Implicit in any design are two general conditions, (1) the input or loading conditions and (2) the limiting or tolerable conditions. While these two conditions are present in conventional design, the problem is much more complex for protective shelter design. It is imperative that the designer understand this distinction.

The situation as far as protective shelters is concerned may be summarized as follows:

1. Input (loading) conditions. Both the blast and the radiation intensity vary independently with weapon yield, range and height of burst. Thus all must be specified as well as other factors.

2. Limiting (tolerable) conditions. The occupant is protected against structural collapse by specifying a limiting deflection and against an excessive amount of radiation by specifying a limit of exposure in rads. The relative physiological effect upon the occupants of exceeding each of these limits is not the same.

While the input and/or limiting conditions may change as a result of advances in weapon technology and delivery capability and of further physiological research, the general design procedures presented herein are still applicable. The structure obviously is dependent upon the assumed input and limiting conditions.

Therefore, it is the purpose of this chapter and Appendix A to discuss in some detail the significance of these varying conditions in order to place the overall problem in proper perspective, and to discuss the influence of local codes and shelter management on the design problem.

1.02 STANDARDS OF PROTECTION

1) Factors in Balanced Design

(a) Variation in Effects with Yield. Table 1.01 and Fig. 1.01 indicate the prompt nuclear radiation associated with various side-on overpressures from various yields of weapons. These calculations are based on the assumption of low air bursts. The table is included only to illustrate the well-known fact that the ranges of the various effects do not vary in the same way with weapon yield. Therefore, the first most obvious problem encountered is that a shelter can be balanced, in the sense defined above, only for one weapon yield.

It has generally been the practice to specify an overpressure level for design purposes and then to design radiation protection for the worst possible intensities of prompt gamma and neutron radiation associated with that overpressure level. Since the prompt radiation at a given pressure level varies with weapon yield, being higher for lower weapon yields, unless some yield is specified this requirement results in the prompt radiation controlling the design. Of course, if the design specification had been to design for a given radiation intensity, the overpressure would control the design.

To eliminate this ambiguity it is necessary to specify a weapon yield. It is apparent from Table 1.01 that the lower the weapon yield the higher the intensity of associated prompt nuclear radiation at any given pressure level. Thus from the standpoint of radiation protection it is logical to choose as low a weapon yield as is reasonable. However, in terms of a mass shelter program and the yields of weapons available today, it is not generally reasonable to consider weapon yields of less than one megaton.

This selection does not eliminate the basic problem, of course; the structure is still not "balanced" to protect equally well from all weapon yields. However, such a structure will withstand all of the effects of a larger yield weapon at a range which is proportional to the cube root of the higher yield.

That is, $R_{(W)} = (W)^{1/3} R_1; \quad W > 1 \text{ MT}$

where $R_{(W)}$ = range of specified overpressure from weapon yield of W
            megatons, ft.

    W   = weapon yield, MT

    R_1 = range of specified overpressure from 1 MT weapon, ft.

The above formulation is possible because the overpressure criterion will govern for larger yield weapons.

A similar formulation for lower yields of weapons is not so simple because both prompt gamma and neutron radiation are involved and these two forms of radiation do not scale in the same way.

(b) Influence of Criteria. The criteria used to design for protection against the various effects of nuclear weapons has a bearing on the question of balanced design.

There are many uncertainties involved in the design of structures to resist the blast from a nuclear weapon as well as many known variables including those of loading, response mode, materials properties, etc. If the current concepts of blast resistant design are employed, no factor of safety, as such, is used. The structure is designed to permit some "allowable" plastic deformation which has been established as being acceptable in the sense that the structure, though it may be damaged, has served its intended function; i.e., it has protected its occupants against the blast effects of the weapon. In the general case for large yield weapons the theoretical collapse load is only slightly larger than that required to produce the "allowable" plastic deformation.

In the case of design for protection against prompt and residual nuclear radiation, the design criterion is some "allowable" dose inside the structure. This dose is generally much less than half the median lethal dose.

Since the uncertainties involved in the design for protection against blast and radiation are probably of the same order, it seems clear that the consequences of exceeding the criteria in each case are not comparable. For purposes of discussion, assume that the collapse load of

a structure can be predicted within a factor of 2 and that the radiation
protection afforded by the same structure can be predicted with the same
accuracy. The consequences of exceeding the allowable dose by a factor of
2 are serious, but not nearly as potentially catastrophic to the occupants
as the consequences of exceeding the true collapse load of the structure.
The fact that there are genetic as well as somatic consequences of a signifi-
cant radiation dose can be used to justify the difference in the criteria.
However, the fact does remain that the question of what constitutes a
balanced design is affected by the design criteria used.

The purpose of the above discussion is not to challenge current
criteria but simply to emphasize that these criteria do have a bearing on
the question of balanced design. What appears to be a balanced design may
not be balanced in terms of the consequences to occupants from exceeding the
physiological criteria established.

(c) Effect of Orientation on Protection. Another aspect of
the problem of "balanced design" involves the effect of weapon-target
orientation on the protection factor which one computes for prompt nuclear
radiation. In general, the structure is designed to withstand the blast
coming from any direction; however, because the protection factor varies
significantly with orientation for a given structure, the radiation shielding
design is most often based on the worst case, or, what is believed to be
the worst case. As a consequence of this approach, the probability that the
shelter occupants will be subjected to a prompt dose in excess of the "allowabl
is less than the probability that the structure will be subjected to a peak
overpressure in excess of the design peak overpressure.

Although this document deals with the design of entrance structures,
the effect of orientation can be illustrated most simply by consideration
of a rectangular structure whose roof slab is flush with the ground surface
(See Fig. 1.02). The worst case for this structure is a burst directly
overhead. Since the solid angle fraction through which the radiation is
being received is relatively large for practical structures, the reduction
factor is due primarily to barrier attenuation.

Assume that the structure is designed to withstand 50 psi peak
overpressure from a 1 MT weapon and associated prompt nuclear radiation.

From Fig. 3.67a of Ref. 1.01, it is apparent that the range at which the 50 psi overpressure level exists varies only slightly with height of burst up to a height of about 5,000 ft. Above that height of burst the range decreases rapidly with height.

The free-field prompt nuclear radiation associated with the range of 50 psi for a low air burst is as indicated in Table 1.01:

Prompt Gamma   43,600 rads

Prompt Neutrons   4,400 rads

Because the values in Table 1.01 are based on a low air burst and an air density of nine-tenths of atmospheric density at sea level under standard conditions, approximately the same intensities of prompt gamma and neutron radiation may be expected at the same slant range (4,600 ft.) up to a height of burst of 4,600 ft. From the standpoint of prompt nuclear radiation, the worst case for this shelter would be a burst directly overhead. The mass thickness required to reduce the prompt dose to some "allowable" dose may be determined by the method outlined in Ref. 1.02. For purposes of illustration, if 20 rads is assumed to be an "allowable" shelter dose of prompt nuclear radiation, a mass thickness of about 700 psf is required when the weapon is detonated directly overhead. The same mass thickness overhead would reduce the prompt dose to less than 1 rad if the weapon were detonated such that a line from the center of the structure to the point of burst were 45° from the vertical. In fact, it can be shown that for the 45° orientation, the weapon would have to be detonated within 2,330 ft. of the shelter to exceed 20 rads inside the structure.

The purpose of the preceding discussion is to demonstrate the significance of orientation on the range at which a given structure will be able to protect its occupants against the two primary effects of interest, i.e., blast and prompt nuclear radiation.

If the weapon were detonated at an altitude of 2,330 ft., the range within which the weapon must fall to exceed the design overpressure on the structure is about 4,600 or 4,700 ft. However, the range within which the same weapon must fall to exceed the "allowable" prompt radiation dose inside is about half that distance. That is, for a height of burst

of 2,330 ft., the overpressure on the structure will exceed 200 psi before
the "allowable" prompt radiation dose would be reached inside the shelter.

This raises the basic question about the probability of obtaining
the worst case.

However, before discussing general probability consideration, it
should be noted that as far as the occupants of the shelter are concerned the
important factor is the total radiation dose that they receive, regardless
of how it is received, i.e., through the shelter proper, through the
entrance system or through a combination of the two. Thus, the worst case
of orientation for the shelter entranceway will not simultaneously be the
worst case for the shelter proper in most cases.

    2) <u>Considerations of Probability.</u> To investigate the probability
of a given event (e.g., the probability of exceeding some overpressure at
the structure) in the most unsophisticated fashion requires knowledge of at
least three parameters:

    a. The location of the designated ground zero (DGZ), i.e.,
       aiming point;

    b. The aiming error in the weapon system assumed;

    c. The range of some specified damage criterion (This in general
       requires knowledge of the yield of the weapon to be employed).

When the target analysis is being conducted from the defensive standpoint
the analyst does not have control over any of these variables. Yet a
probability study can be informative.

With regard to the first parameter mentioned, i.e., the location
of ground zero, it is not reasonable to assume that the shelter under
consideration is a target, per se. That is to say, it is not reasonable to
assume that it is at the DGZ. A more reasonable assumption for the case of
a shelter for the general population is that a typical shelter is at some
distance from the DGZ. On the other hand, it is not reasonable to assume
that the shelter is too far from the DGZ primarily because there is no need
to provide a shelter which will withstand 50 psi and associated close-in
effects to serve a population located at a great distance from a reasonable
target area (e.g., a critical military installation or a major population
center).

A more sophisticated approach would require a study of a complex of shelters distributed in various patterns; i.e., various models of population and thus shelter distributions would be required. However, the basic ideas involved can be obtained from a study of one shelter entrance as is shown in Appendix A.

From such a study, it is apparent that, in the general case, the probability of the worst case orientation for prompt nuclear radiation is small compared to the probability that the structure will be subjected to the design overpressure under the same set of conditions. Further, because the range of various effects do not vary in the same way with weapon yield and height of burst, it can be seen that a different "balance" would be required for each set of design assumptions. Therefore, a "balanced design" in the strict sense is not possible.

3) <u>Recommended Procedure</u>. In view of the dilemma posed by the preceding considerations, the following procedure is recommended:

a. Determine the worst case orientation for prompt nuclear radiation from the architectural configuration of the entranceway. It is possible to do this in most cases without too much calculation.

b. Determine how far away the weapon must be detonated to produce the design overpressure on the surface of the ground at or near the structure for that specific orientation.

c. Calculate the prompt nuclear radiation at the slant range determined by step b.

Although this procedure does not "balance" the design, it does provide a rational approach to the problem which will result in a logical solution.

1.03 HUMAN TOLERANCES

1) <u>Blast</u>. Recent research on mortality in small animals subjected to sharply rising overpressures (Ref. 1.03) has revised somewhat the estimate of the effects of overpressure on human beings. A summary of the data included in Ref. 1.03 is tabulated below.

p(max) psi side-on or reflected	Probable Biological Effect
5-45	1-99% eardrum rupture
15-25	Threshold of lung hemorrhage
35-65	1-99% mortality

The latter two pressure ranges apply only to sharply rising pressure of "long" (> 400 msec) duration.

The side-on overpressure level for which the shelter under consideration is designed is presumed to be 50 psi which is about the median lethal overpressure. Therefore, it is apparent that blast closure devices must be installed in all openings leading into the structure. Leakage of gas at high pressure through cracks, etc., around such closure devices might occur. The pressure rise inside the shelter would not be sharp; however, the maximum pressure in the structure must be kept to less than approximately 10 psi to prevent excessive eardrum damage and secondary blast damage to personnel by their being knocked about inside the shelter.

Although this report does not deal with the design of the shelter proper, it is noted in passing that a maximum overpressure of 5 psi, even though it is not applied as a shock, can cause considerable damage to lightly constructed interior partitions thus creating a hazard to personnel in the shelter.

2) Nuclear Radiation.

(a) Prompt. A summary of the clinical effects of acute ionizing radiation doses is included in Table 1.02. This table is reproduced from Ref. 1.01 (Table II.III, p. 501).

As stated previously, there are genetic as well as clinical effects of such radiation to be considered. If only somatic damage were of interest the "allowable" dose might be as high as 100 rads. When genetic damage is considered, the "allowable" dose under emergency conditions must be set at some lower figure.

The National Committee on Radiation Protection and Measurements (Ref. 1.04) has taken the position that the concept of permissible exposure cannot be applied in the usual sense in such emergencies as a nuclear war,

the breakdown of a nuclear reactor, or an accident in a nuclear energy
industrial establishment. Their report states (p. 2), "The problems of
controlling exposure to radiation in a nuclear war are inordinately complex,
and their solution is not susceptible to rules of thumb or to the principles
of radiation protection based on past experience. It is not possible,
for example, to assign values for 'permissible dose'." The document
further states "The alternative to prescribing permissible doses for
specific tasks or for specific groups of people is to prepare guidelines
describing the consequences of exposure to the amounts of radiation which
might be encountered. . . . . This report was prepared to help civil
defense officials make proper decisions in preparation for nuclear warfare
and during the first few months after an attack."

Ref. 1.05 states in Section VII, Radiation Shielding, paragraph
B, "In shelters offering resistance to blast, the shielding required to
adequately reduce the initial gamma and neutron radiation shall be
calculated at the range of the design overpressure, using methods approved
by the Office of Civil Defense. Using these methods, the inside dose
from initial radiation shall not exceed 20 rad."

Since some permissible dose from initial gamma and neutron
radiation must be assumed in order to design a shelter, and in lieu of any
more valid information, a permissible dose of 20 rads has been assumed for
this study.

(b) Residual. The protection factor against radiation from
residual contamination which will be provided by designing the shelter to
protect its occupants from close-in effects will be higher by a couple of
orders of magnitude than the minimum specified (100) for fallout shelters.
However, at the 50 psi range the accumulated dose from fallout gamma is
very high and the minimum protection factor is simply not adequate.

It is noted that according to current estimates a dose of
between 30 and 80 rads is required to double the rate at which spontaneous
mutations are already occurring in humans. (See Art. 11.200 of Ref. 1.01).
Above that level the number of gene mutations are believed to be approxi-
mately proportional to the total radiation absorbed by the parents. A
dose of 100 rads is the threshold of somatic damage to humans. In this

regard, some personnel in the shelters may have to be exposed to additional doses for various purposes such as rescue and repair operations. Keeping the total accumulated dose (prompt plus residual) in the shelter well below 100 rads will not only reduce the genetic damage, but also will reduce the clinical damage to those personnel who may have to perform recovery operations in a less sheltered environment.

Therefore, in the absence of any specific criteria, a residual radiation dose of 20 rads has been assumed for this study. Thus the total accumulated dose (prompt plus residual) has been assumed to be 40 rads which is significantly less than the 100 rads discussed in the preceding paragraph.

3) _Air Quality._ A considerable amount of research has been done in the area of environmental engineering for shelters (Ref. 1.06). Of course, much of the work done on air quality control in submarines and space capsules is directly applicable. Ref. 1.07 contains a good summary of the effects of three significant variables on shelter occupants. Tables 1.03, 1.04 and 1.05 concerning the effects of oxygen deficiency, carbon dioxide, and carbon monoxide content were extracted from Ref. 1.07.

In addition to the above, the effects of heat and cold on shelter occupants have been studied thoroughly. Table 1.06 taken from Ref. 1.06 lists acceptable and tolerable thermal limits for healthy people at rest. These limits are expressed in terms of effective temperatures (E.T.) which are not the same as the dry bulb temperature. Table 1.07 taken from the same reference lists the effective temperature as a function of dry bulb temperature and relative humidity.

Based on these studies, standards of air quality for design purposes may be established as follows:

Oxygen Content	17% min.
Carbon Dioxide Content	1.5% max.
Carbon Monoxide Content	0.01% max.
Effective Temperature	
Lower Limit	50° F.
Upper Limit	85° F.

These standards are included, even though this report does not cover the design of the mechanical system, in order to provide the necessary

background for consideration of intake and exhaust structures and their possible effects on the shelter entrance design.

1.04 COMPLIANCE WITH LOCAL BUILDING CODES

It has been assumed that existing local regulations will apply to the design of shelters built for civilian occupancy and thus control certain aspects of the entrance and opening designs developed under this contract. Compliance with local regulations is therefore desirable in order to insure widest acceptance of the designs, especially since the applicable regulations are generally uniform throughout the country and represent empirical standards of safety or comfort not subject to rigorous analysis and significant improvement. However, the use of this design criterion automatically eliminates a number of entrance solutions such as ladders, slides, firehouse poles, etc., which present an accident risk considered unacceptable by code authorities.

With reference to entrances, the building codes define minimum width and height, stair details, slope of ramp, number and locations of exits, etc. These dimensional restrictions are based on long experience with disaster prevention and insure the least probability of casualties under the type of panic conditions which may obtain at alert time. However, it must be noted that the exit codes were developed to enforce the safety of human traffic moving outward from the fire risk or threat generated in a crowded interior to the relative safety of the outdoors. The exit codes therefore imply a lack of traffic restraint beyond the exit bottleneck. Precisely the opposite situation exists in the shelter case since traffic will flow from the unrestricted open into the relatively congested conditions of the shelter and one must assume some feedback affecting traffic in the entrance system. Hence the current exit codes should be considered as representing relatively liberal restrictions not to be exceeded in any circumstance. Similarly the traffic estimated for stated dimensions in the codes is likely to be on the high side.

With reference to ventilation openings, the codes generally apply to comfort levels somewhat greater than the minimum specified for shelter conditions by the Office of Civil Defense, Department of Defense.

1.05   SHELTER MANAGEMENT AND OPERATIONAL PROCEDURES

1) <u>General</u>. It is the purpose of this section to discuss only
those aspects of shelter management and operational procedures that relate
to the problem of designing low-cost protection of shelter openings. It
is, of course, obvious that any large scale program of shelters for civil
defense purposes would of necessity require a rather extensive and complex
shelter management organization not only for each individual shelter, but
also for the shelter complex within a given level of local governmental
authority. The functions of such a shelter management organization and
the operational procedures would be indeed varied and would include, as a
minimum: security, communications, medical, messing, berthing, maintenance,
etc.

A discussion of the overall shelter management organization is
beyond the scope of this report. However, there are several facets of the
shelter management program and the operational procedures that would be in
effect before occupancy, during loading of the shelter for occupancy and
during the occupancy that do indeed affect the entrance configuration, the
blast closure, the type of operation, etc. Several assumptions must be
made on these as they affect the maintenance of the closures before occu-
pancy; the control of the flow of people during access to insure safe
entry into the shelter, prevention of overloading, prevention of panic,
and the closing of the door prior to the arrival of the blast wave; to
insure the maintaining of the blast integrity after closure; and to insure
egress after the period of occupancy.

It must be assumed for purposes of this report that as a minimum
the shelter management provides a security and a maintenance capability.

2) <u>Security</u>. The security capability as a minimum must insure
the opening of the door when required for access, the orderly movement of
people through the entranceway into the shelter proper and away from the
entrance, the prevention or minimization of panic, the closing and securing
of the door after entry, the blast integrity during the occupancy period,
and the opening after the occupancy period.

These considerations influence the entrance configuration
(i.e., ramp or stairs, single or double width corridor, etc.; horizontal
or vertical closure, swinging in or out, etc.) and the method of opening
the door either as designed or under emergency conditions.

3) <u>Maintenance</u>. The maintenance capability as a minimum
must insure pre-disaster maintenance of the closure units and removal of
debris to allow free movement and complete sealing of the closure; the
pre-disaster removal of debris from stairs or ramps and corridor; the
pre-disaster maintenance of fuel supply, emergency power, and lighting
fixtures for illumination during entry; and the provision of tools to
jack open or dismantle the door, or cut-through for emergency escape in
the event the door fails to open after the emergency.

These considerations influence the type of closure units, their
support and sealing appurtenances, their method of actuation and operation,
etc.

4) <u>Occupancy</u>. The type of occupancy, i.e., age, sex, and physical
well-being, will materially affect the entrance design. If the occupants
were all young and vigorous males, a pole for sliding ingress and a rope
ladder for egress would be satisfactory as a minimum. For similar occupancy,
a vertical entranceway with a permanent ladder or a chute would be
permissible. However, for heterogeneous occupancy, i.e., male and females
of varying ages, stairs and possibly ramps would be required.

Aged or infirm occupants pose special problems. Persons entering
on crutches can be handled satisfactorily. Access in a wheel chair would
require ramps with a relatively gentle slope. Except under an emergency
evacuation of the shelter, egress would probably be orderly and assistance
would pose no particular problem for occupants in wheel chairs. Stretchers
or litter cases would not only require relatively gentle slopes as in the
case of wheel chairs, but would also require wider corridors and/or less
sharp bends in order to negotiate the corners on the ramps and/or corridors.

No recommendations have been made in this report for entranceways
to accommodate occupants entering in wheel chairs, stretchers, and/or
litters.

5) <u>Ingress/Egress After Attack</u>. From the standpoint of ingress
and/or egress after an attack, as long as the closure unit has not sustained

excessive plastic deformation or become jammed, there is no particular problem. Ingress may be required after an attack to accept late arrivals, transferees from other shelters, medical, repair, or other personnel. Egress may be required for medical, repair, rescue, decontamination, or other personnel to perform recovery tasks and to remove sick, injured, or dead.

If the attack has been of a contaminating type, i.e., radioactive fallout, biological, and/or chemical, provision would have to be made for decontaminating entering personnel and maintaining integrity of the internal environment. It is assumed that air locks and decontamination facilities, if provided, would be provided on the protected shelter side of the blast closure. These have not been included as part of the entranceways designed herein. It is further assumed that adequate water supply, shielding, and provision for disposal of contaminated water and clothing from the decontamination facility would be provided.

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TABLE 1.01

PROMPT NUCLEAR RADIATION ASSOCIATED WITH VARIOUS SIDE-ON OVERPRESSURES FROM VARIOUS YIELDS OF WEAPONS (LOW AIR BURSTS)*

Yield	Range(ft)	Prompt Gamma(Rad)	Prompt Neutron(Rad)	Total Prompt (Rad)
30 psi Level				
100 KT	2,600	54,000	33,000	87,000
1 MT	5,600	11,800	750	12,550
10 MT	12,000	140	~ 0	140
50 psi Level				
100 KT	2,140	121,500	102,000	223,500
1 MT	4,600	43,600	4,490	48,000
10 MT	9,900	1,400	0	1,400
100 psi Level				
100 KT	1,620	350,000	400,000	750,000
1 MT	3,500	215,000	45,000	260,000
10 MT	7,500	23,800	200	24,000

*These data were calculated from "The Effects of Nuclear Weapons - 1962" assuming that the height of burst were low enough so that the slant range is approximately equal to the horizontal distance from ground zero but high enough so that shielding by dust thrown up by the detonation is negligible. The air density is taken as 0.9 times the density at sea level.

TABLE 1.02

SUMMARY OF CLINICAL EFFECTS OF ACUTE IONIZING RADIATION DOSES

Range	0 - 100 rems Subclinical range	100 - 1000 rems Therapeutic range			Over 1000 rems Lethal range	
		100 - 200 rems Clinical surveillance	200 - 600 rems Therapy effective	600 - 1000 rems Therapy promising	1000 - 5000 rems Therapy palliative	Over 5000 rems
Incidence of vomiting	None	100 rems:5% 200 rems:50%	300 rems:100%	100%	100%	
Delay time	--	3 hours	2 hours	1 hour	30 minutes	
Leading organ	None	Hematopoietic tissue			Gastrointestinal tract	Central nervous system
Characteristic signs	None	Moderate leukopenia	Severe leukopenia; purpura; hemorrhage; infection. Epilation above 300 rems.		Diarrhea; fever; disturbance of electrolyte balance	Convulsions; tremor; ataxia; lethargy.
Critical period post-exposure	--	--	4 to 6 weeks		5 to 14 days	1 to 48 hours
Therapy	Reassurance	Reassurance; hematologic surveillance	Blood transfusion, antibiotics	Consider bone marrow transplantation.	Maintenance of electrolyte balance	Sedatives
Prognosis	Excellent	Excellent	Good	Guarded	Hopeless	
Convalescent period	None	Several weeks	1 - 12 mos.	Long	--	
Incidence of death	None	None	0 - 80%(var.)	80 - 100%(var.)	90 - 100%	
Death occurs within	--	--	2 months	2 months	2 weeks	2 days
Cause of death	--	--	Hemorrhage; infection		Circulatory collapse	Respiratory failure; brain edema.

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TABLE 1.03

EFFECTS OF OXYGEN DEFICIENCY
(FROM REF. 1.05)

Oxygen Content of Inhaled Air, Percent	Effects
20.9	No effects; normal air
15	No immediate effects
10	Dizziness; shortness of breath, deeper and more rapid respiration, quickened pulse, especially on exertion
7	Stupor sets in
5	Minimal concentration compatible with life
2.3	Death within a few minutes

TABLE 1.04

EFFECTS OF CARBON DIOXIDE - OXYGEN CONTENT NORMAL
(FROM REFERENCE 1.05)

Carbon Dioxide Content of Inhaled Air, Percent	Effects
0.04	No effects; normal air
2.0	Breathing deeper; air inspired per breath increased 30 percent
4.0	Breathing much deeper; rate slightly quickened; considerable discomfort
4.5-5	Breathing extremely labored; almost unbearable for many individuals; nausea may occur
7-9	Limit of tolerance
10-11	Inability to coordinate; unconsciousness in about ten minutes
15-20	Symptoms increase, but probably not fatal in one hour
25-30	Diminished respiration; fallout of blood pressure; coma; loss of reflexes; anesthesia; gradual death after some hours

TABLE 1.05

EFFECTS OF CARBON MONOXIDE
(FROM REFERENCE 1.05)

Carbon Monoxide Content of Inhaled Air, Percent	Effects
0.02	Possible mild frontal headache after two to three hours
0.04	Frontal headache and nausea after one to two hours; occipital (rear of head) headache after two and one-half to three and one-half hours
0.08	Headache, dizziness, and nausea in forty-five minutes; collapse and possible unconsciousness in two hours
0.16	Headache, dizziness, and nausea in twenty minutes; collapse, unconsciousness and possible death in two hours
0.32	Headache and dizziness in five to ten minutes; unconsciousness and danger of death in thirty minutes
0.64	Headache and dizziness in one or two minutes; unconsciousness and danger of death in ten to fifteen minutes
1.28	Immediate effect; unconsciousness and danger of death in one to three minutes

TABLE 1.06

ACCEPTABLE, AND TOLERABLE THERMAL LIMITS FOR HEALTHY PEOPLE AT REST PROPERLY CLOTHED

Limits expressed in terms of Effective Temperature (E.T.), which is the temperature of saturated air with minimum air movement (See Table 1.07)

Lowest temperature endurable in cold weather for at least two weeks in emergencies	35° E.T.
Possible chilblain, or shelterfoot	35-50 E.T.
Lowest acceptable for continuous exposure. Manual dexterity may be affected	50 E.T.
"Optimum" for comfort, with 60% relative humidity or less	68-72 E.T.
Perspiration threshold. Acceptable for continuous exposure	78 E.T.
Endurable in emergencies for at least two weeks. Possible heat rash in prolonged exposures	85 E.T.
Possible heat exhaustion in unacclimatized people	88 E.T.
Possible heat exhaustion in acclimatized persons	92 E.T.

Extracted from "Tolerance Limits of People for Cold, Heat, and Humidity in Underground Shelters," by C. P. Yaglou, Ref. 1.06.

TABLE 1.07

EFFECTIVE TEMPERATURE

Effective Temperature (E.T.) is an empirical heat index based on human sensations. It combines the temperature, humidity, and movement of air into a sensibly equivalent temperature of saturated air with minimal air motion. In unventilated-underground shelters where the air is almost saturated with moisture, the E.T. will be practically the same as the dry bulb temperature. For unsaturated atmospheres the E.T. can be computed from the table below. (Ref. 1.06)

Dry bulb temperature °F	E.T. for relative humidities of				
	60%	70%	80%	90%	100%
50	50	50	50	50	50
60	58	59	59	60	60
70	67	67	68	69	70
75	71	72	73	74	75
80	75	76	77	79	80
85	79	80	82	83	85
90	83	85	86	88	90
95	87	89	91	93	95
100	90	93	95	98	100

Side-On Overpressure, p_{so}, psi.
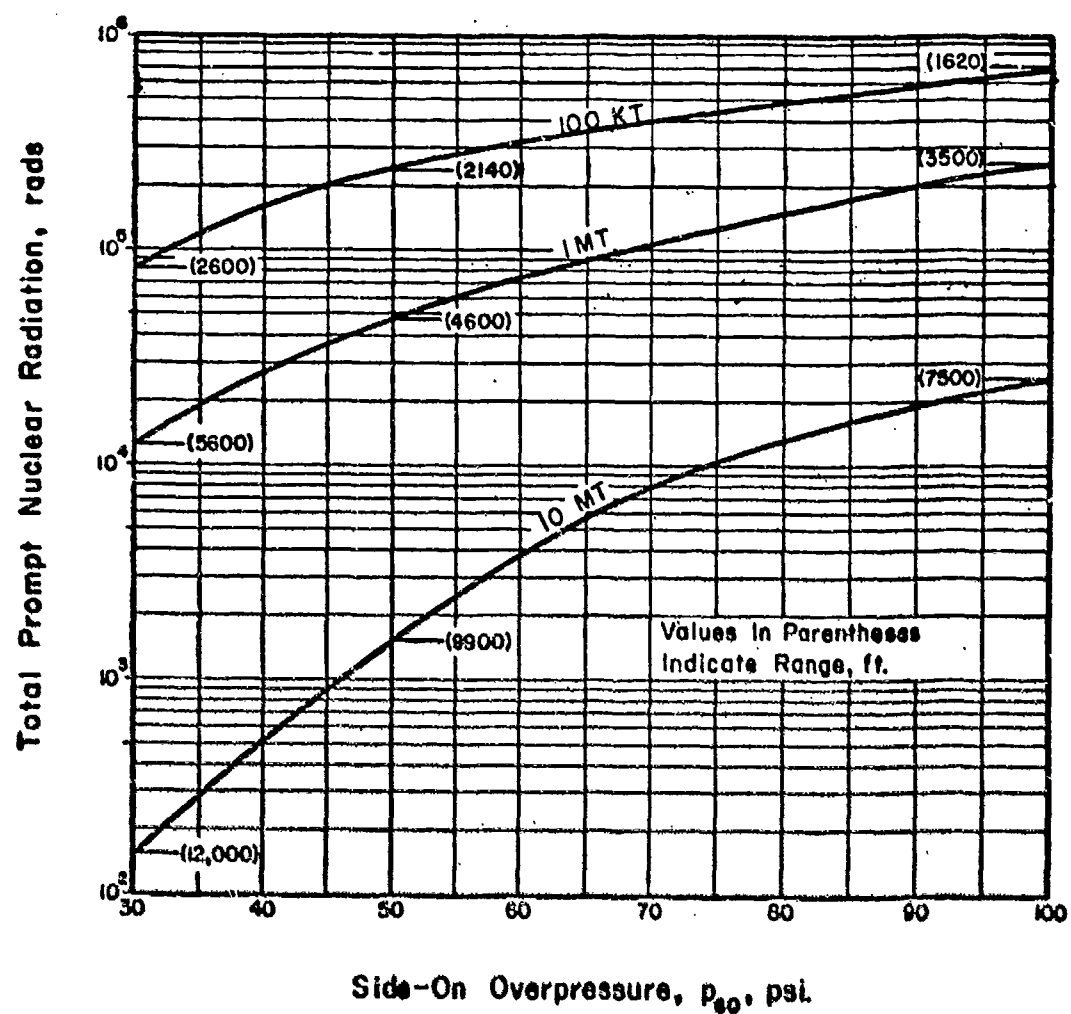
FIG. 1.01 TOTAL PROMPT NUCLEAR RADIATION VS SIDE-ON OVERPRESSURE

VS WEAPON YIELD

24.

PLAN

SECTION A-A
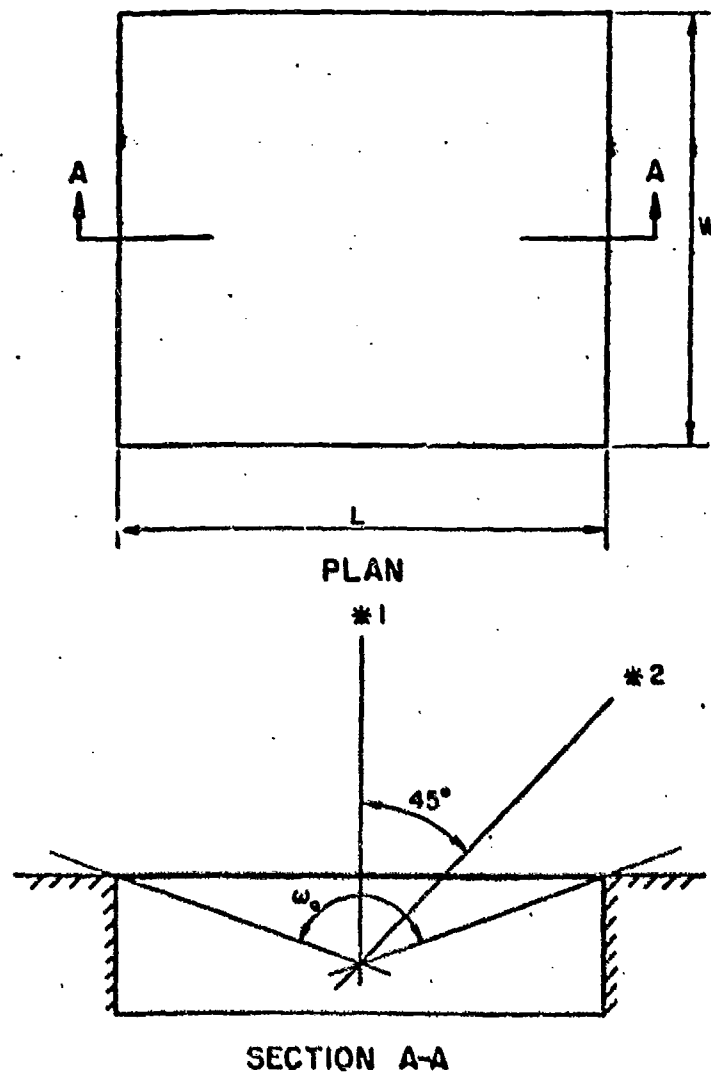
Case I ; Burst Overhead
Case 2 ; 45° Orientation

FIG. 1.02 RECTANGULAR STRUCTURE WITH ROOF SLAB FLUSH WITH
GROUND SURFACE; TWO ORIENTATIONS WITH RESPECT TO POINT OF DETONATION

CHAPTER 2. SHELTER ENTRANCE SYSTEMS

2.01 INTRODUCTION

The final selection of the type of entrance best suited for a specific situation can be made only after a number of different factors have been considered. Many of these factors are inter-related and do not lend themselves to independent consideration. However, in order to discuss the various factors it is essential that they be isolated and that their mutual effect be considered only in the final synthesis.

It is desirable to summarize the various factors affecting the design of entrance systems before examining the individual factors in detail. Such a summary is indicated by the following tabulation:

1) Site Conditions.

    a. Terrain - level or sloping

    b. Building density and proximity

    c. Relation of shelter to outside access level

2) Capacity and Safety.

    a. Shelter system (Isolated or integrated)

    b. Warning time

    c. Decontamination area

    d. Interlock

    e. Type and location of doors

    f. Widths of doors and corridors

    g. Number of doors

    h. Type of depth element

        1) Stairs

        2) Ramp

    i. Psychological considerations

3) Structural Resistance

    a. Overpressure

    b. Incidence angle

    c. Turns or bends in corridor element

    d. Negative phase

4) Radiation Protection
   a. Through door
   b. Turns or bends in corridor element
   c. Shields or barriers
   d. Length of corridors

5) Door Operation
   a. Simplicity
   b. Effectiveness
   c. "Buttoning Up" time
   d. Vulnerability to damage or blocking

6) Cost

The objective of this chapter is to state the specific assumptions made regarding the shelter entrance system. Discussed are the elements of entrance systems, the depth of the structure relative to the outside grades, the ingress traffic rates, and the operational concepts of the entrance system as they influence the design of the entrance system.

The concept of the entrance system in this report is that of an integrated self-supporting system consisting of several elements. The door frame is included in the system although its support may be incorporated in the shelter structure proper. The discussion is appropriate to buried structures in general rather than to a particular structure.

The capacity of the entrance systems is based on the modular principle. A module is rated in terms of its capacity, i.e., the number of persons per minute which it can accommodate. As discussed in Sec. 2.04 of this chapter, this is a varying quantity with time. Therefore the number of entrance system modules required will be a function of the warning time and the capacity of the shelter proper.

Although no consideration is given in this report to the number of entrances required for a particular shelter, a few comments are in order regarding the requirement of an emergency escape and the orientation of entrances if more than one are required. In order to insure opening of the door after an attack, the door structure should be restricted to relatively small permanent deformations or should be designed such that

the deformations do not prevent the door from being opened. If plastic
deformations are designed for and/or occur, provision must be made
either for jacking the door open or cutting it away, or for separate
emergency escape means.

If the DGZ (designated ground zero) is known or can logically
be assumed, all entrances should be oriented away from the DGZ, in order
to minimize the levels of blast and nuclear radiation. Similarly, if
the capacity of the shelter is such as to require more than one entrance
and if the DGZ is unknown, the entrances should be oriented at least
90° apart. To reduce the debris hazard the entrance structures should
be connected to opposite ends or sides of the shelter.

2.02 ELEMENTS OF ENTRANCE SYSTEMS

The protection of the shelter openings has been restricted to
the structural and mechanical elements of the entrance system between
the ground surface and the enclosing structural envelope (shell) of the
shelter proper. These include the following:

1) Surface Transition Element. At the ground surface where
the entranceway system emerges, attention must be paid to its location
with respect to buildings which might become a debris and/or incendiary
hazard, its orientation with respect to any most probable ground zero,
ground water conditions, surface drainage conditions, backfill compaction,
absence of vertical protuberances presenting a sizable "sail" area to
the blast wave, proximity to utility lines which when damaged might prevent
ingress and/or egress, structural strength, etc.

2) Depth Element. The depth element provides for descending
to the level at which the shelter proper can be entered. It may consist
of ramps or stairs and/or bends or turns. The dimensions (widths, heights,
slope, rises, tread, etc.) are in general dictated by codes whose influence
is discussed in Chapter 3.

3) Corridor Element. A corridor element may be required
between the riser element and the shelter for one of several reasons,
e.g., to permit one riser element to serve more than one shelter, to
provide a location for machinery that should be isolated from the shelter,
or to provide additional turns and/or lengths for radiation and blast
attenuation that are not provided in the depth element.

The actual configuration of the corridor element is determined by the requirements for the perturbation of the blast wave and the attenuation of both the initial and residual radiation. These configurations are discussed in Chapters 5 and 6.

4) **Interlock Element**. An interlock element provides for late arrivals to enter the shelter without exposing the people in the shelter to the blast wave. The actual interlock system may or may not be considered a separate element, as the only major feature of an interlock is two doors with a holding space between. Hence, it could be a separate element within the shelter entrance system with two corridor doors and an intervening corridor, or it could be an exterior door at the surface and a corridor door with the intervening corridor and depth elements serving as the storage area.

5) **Shelter Transition Element**. This element simply makes the transition from any of the other elements (corridor or depth) to the shelter proper. In some situations, when the blast load on the door is transmitted directly to the shelter, the shelter transition element will be a structural element.

6) **Door Element**. The door element consists of the door itself, as the means of excluding positively the blast pressure; the hinges, rollers, or other supporting mechanisms; sealing devices to prevent flow of air under response and rebound; the supporting frame; and any mechanism for manual or automatic operation of the door. The required strength or resistance is a function (1) of the orientation of the door, and/or the location of the door; (2) of the ratio of the positive phase duration of the blast wave to the natural period of the door: (3) of the span and length of the door; and (4) of the method of support; i.e., simple or fixed, in one or in two directions.

Since the problems associated with the design of the door element are a significant part of the total problem of the entrance system, a subsequent section has been devoted solely to a discussion of closing mechanisms.

7) **Decontamination Element**. Some provision for a decontamination area must be included in any large shelter complex. While it might not

be used upon the initial entry of shelterees, it likely would be used
during the post-attack operation. Such an area might be incorporated
within the shelter proper or within a separate and alternate entrance
corridor. A discussion of the design criteria for a decontamination
area is beyond the scope of this report.

2.03 SITE CONDITIONS

The site conditions of the terrain, the proximity of other
structures, the location of utilities and the relation of the shelter
with respect to the outside access level materially affect the selection
of the entrance system. These conditions themselves may affect or be
affected by other entrance system requirements, e.g., capacity and
safety, structural resistance and radiation protection. While these
factors must be separated for discussion, the final selection of a
particular entrance system is dependent upon the synthesis of all of
the pertinent factors.

It is impossible to have a single entrance system that will
satisfy all the possible site conditions and shelter types that may be
encountered. Therefore, for discussion purposes in this chapter, four
idealized situation or cases have been assumed. It is believed most
site conditions and shelter types can be idealized to correspond to one
of these four cases. All cases portray buried or covered structures,
with 4 ft. of overburden and an 8 ft. clear height from the shelter
entry level to shelter ceiling. The four cases are described as follows:

Case I   Outside access level 12 ft. above the shelter entry
          level. Ground surface is approximately level.

Case II   Mounded or semi-buried; outside access level 6 ft.
          above the shelter entry level.

Case III Mounded, earth covered; outside access level and
          entry level at same elevation.

Case IV   Covered or buried shelter; entrance is through a
          vertical door, as in a basement wall or other
          vertical surface.

When depth elements are used, two types are considered, i.e.,
a 10 percent ramp and a 7 3/4 in. riser - 9 1/2 in. tread stairs. As
discussed in Chapter 3 these represent the maximum slopes for egress and
ingress.

The four cases are presented in Figs. 2.01 and 2.02. As shown
in Fig. 2.01, Case I and Case II may be used for any floor to ceiling
heights, as well as for multiple stories. A similar situation is
applicable to Case III (Fig. 2.02). The limiting condition is that
direct access is made 8 ft. $\pm$ below the ceiling of the upper story.
If the story height is greater than 8 ft., then an inside stairs is
required as in I(b).

For mounded construction, Cases II and III, two side slopes
are illustrated, i.e., a 1:1 and a 2:1. While there are advantages to
both slopes as far as the door is concerned, the 2:1 slope is about as
steep as can be attained when the stability of soil is considered.

Figs. 2.03, 2.04, 2.05 and 2.06 show the four idealized
situations, Cases I, II, III and IV, respectively. Both a stairs and
a 1:10 ramp are shown for Cases I and II, while a horizontal corridor
only is shown for Case III and IV. Doors are shown only at the surface
(except for Case IV) in order to compare the approximate lengths.
Vertical doors, of course, could be installed in any of the corridor
elements. However, since the site conditions do not materially affect
the design of interior doors, they are not considered in this section.
It also is important to note that while the design pressure is different
for the exterior doors at different angles of incidence, all interior
doors must be designed for a reflected pressure. Refer to Chapter 5
for a more complete discussion.

It should be noted also that some of the drawings in Figs.
2.03 and 2.04 indicate a depth element only. A corridor element of
any desired length may be incorporated in the design, as required by
other considerations. Fig. 2.03(b) has only a depth element, whereas
Fig. 2.03(c) has a corridor element also.

The use of a 1:10 ramp for Case I is not practical as shown
in Fig. 2.03(a). While, as previously stated, an interior door could be
used, the surface opening is so large that it becomes impractical. It
is believed that in any cases where a ramp must be used, such as for a
hospital, that either Case II or III becomes more practical, particularly

Case III. Stairs become a very practical solution for Case I, as shown
in Fig. 2.03(b) and (c). The major advantage is that the door is
relatively short and parallel with the ground surface. Since it is
flush with the ground it is designed only for the side-on overpressure
rather than a higher reflected pressure when at some angle to the
horizontal.

Fig. 2.04 compares the use of a stairs and a ramp for Case II.
The stairs again appear the more reasonable solution if a long corridor
is not required by other considerations. Fig. 2.05 indicates that even
with a 2:1 soil slope the door is not unreasonably long. If fill were
available this case probably would be preferable for hospital construction.

While it is impossible to draw definite conclusions as to
which type construction may be most desirable for a specific case,
without actually computing the cost of the entire entrance structure and
without weighing the relative blast and radiation protection, some
general conclusions may be drawn at this point. In general, the stairs
are likely to be most desirable for general use. It permits more
flexibility in that the corridor element may be as long or have as
many turns as is desired.

The advantages and disadvantages of the four cases may be
summarized as follows:

Case I

1. The 1:10 ramp requires too long a door or exposed opening.

2. The flush horizontal door may be designed for the least
   pressure of any configuration.

3. This case is most applicable when the ground above is to
   be used for some purpose such as a playground, parking, etc.

Case II

1. Probably the best solution for most cases in that the
   construction makes use of waste soil.

2. May not be suitable for multi-purpose use of land due to
   mounding around the shelter.

3. Use of the stairs may be desirable particularly when land
   is at a premium or in a congested area.

Case III

1. Excellent for hospitals and other facilities requiring gradual entrance slope.

2. Requires an excessive amount of fill from a borrow pit.

Case IV

1. Restricted use only

2. The door through the wall must be considered only as a direct access door from the building.

3. Since this case is very susceptible to blocking due to debris, it is essential that an additional exit be provided, preferably as far away from the building as possible.

2.04 ENTRANCE TRAFFIC RATE

The entrance traffic rate, i.e., the traffic flowing past a given point of a shelter entrance, uniquely describes the capacity of an entrance system and provides the best criterion for comparing system efficiencies or costs and for selecting optimal entrance systems as a function of such independent variables as alert time, contributing population density and distribution, shelter capacity and number of entrances.

The traffic flow rate is expressed as the number of people moving per unit width (or foot of width) per minute and, as will be discussed in Chapter 3, varies according to traffic density or velocity, as well as the width and slope of the entrance system. For instance, assuming a minimum effective width of 22 in. for the access and door elements and an "approved" stair configuration, the _average_ entrance rate works out to be 40 persons per minute for a density of 1 person per 6.5 square feet and a velocity of 1.5 miles per hour. The _peak_ traffic rate for the same conditions of width and density is 60 persons per minute corresponding to a velocity of 2.25 miles per hour.

The data and observations on which traffic flow is based are reasonably consistent and can be easily improved by ad hoc experimentation under simulated conditions. These data are discussed and the applicable traffic rates are tabulated in Chapter 3. The criterion involves both a peak and an average rate estimated from available data.

The use and validity of these two rates are predicated on the assumption that the traffic through the entrance system will follow a distribution curve with a slow buildup following the alert siren and peaking somewhat before the end of the alert period. Traffic distribution curves will of course vary widely according to local site conditions, but total traffic can be estimated by multiplying the average rate by the number of minutes warranted by these conditions.

2.05 MECHANICAL SYSTEMS OF DOOR CLOSURES

1) General. In other sections of this report material is presented which permits the designer to choose from a variety of configurations and several different materials the door which will be required to resist the loads imposed. The choice which is made from among all of the possible solutions may be influenced to a considerable degree by other factors. The ideal type of door would be simple to operate, would be comparatively cheap, would require virtually no maintenance and would make an absolute seal. These requirements tend to work against one another.

In the final analysis the optimum closure must meet certain requirements with respect to initial cost, maintenance, safety, sealing and support. In addition to these items it must satisfy certain psychological aspects of entrance and egress. For the wide variety of choices available it is impossible, without consideration of a specific case, to discuss in detail the many possible solutions. The final choice will depend to a great extent on the importance assigned to the several items mentioned above.

For purposes of discussion the general systems of door closure have been separated into either sliding or hinged.

2) Hinged Doors. Within this category consideration must be given to doors which swing back into the entrance corridor or into the shelter area. It is possible, depending upon the configuration of the entrance tunnel, that this type of door could also be mounted somewhere along the tunnel. Should this be the case the factors enumerated in the following still hold. The basic differences between the two systems occur in the consideration of support requirements, sealing and in the psychological considerations.

(a) Cost. For the door proper there is no particular difference in the makeup regardless of whether the door swings into the entrance corridor or into the shelter area. The basic structural system would be identical and therefore cost would not be a consideration. The most important consideration in the cost for this type of door is the need for automatic closure devices as opposed to manual operation.

(b) Maintenance. Maintenance for this system should be a minimum provided the proper materials are chosen for the door hinge, the sealing material and the latching devices.

(c) Safety. This particular consideration is difficult to discuss in a straightforward manner because it is intimately connected to the psychological aspects of the problem. A door swinging back into the entrance corridor provides certain advantages since anyone in front of the door at the time of closure would be swept by the door into the shelter. The particular disadvantage of this system is that in the event of panic or accidental movement the door could be closed prematurely by those seeking entrance to the shelter. The first requirement then is that some positive steps must be taken to prevent such an occurence.

On the other hand in the case where the door swings into the shelter area this difficulty does not occur since those seeking entrance to the shelter automatically keep the door open. The problem of closing a door which is hinged in this direction presents a very serious problem. Such a system would place a great deal of pressure on the person responsible for closing the door at the proper time. It would be his responsibility to dissuade those seeking entrance in order to be able to close the door for the safety of those already in the shelter. One can easily visualize the difficulty of carrying out the mechanical operation under these circumstances and this aspect of the problem will not be discussed further.

In both cases under consideration it would be necessary to provide for a change in elevation between the tunnel floor and the shelter floor. One case would require a step up into the shelter and the other would require a step down. This change in level is required in order to be able to provide sealing at the bottom of the door to prevent

any buildup of pressure within the shelter. A change in elevation can be
provided for most easily with a hinged plate, either steel, aluminum
or timber, similar to that shown in Fig. 2.07. This plate could easily
be flipped out of the way when the door is finally closed. More compli-
cated systems could be devised easily to accomplish a safe access to
the shelter. Such systems would involve considerably more cost without
adding significantly to the operation of the shelter.

(d) Sealing. Under this heading consideration must be
directed to both the positive and negative phases of the blast. The
discussion herein is based on the assumption that the hinge is expected
to support only the weight of the door and not to resist any of the load
from the blast. On the contrary in some cases it is specifically designed
as a flexible arrangement to permit the door to seat itself properly
and to provide a better deal. In the event that a system is designed so
that the hinge does resist some of the blast load, special care will be
required to insure proper sealing.

All of the systems for sealing, as well as for support which
are discussed later in this section, require some adaptation of the basic
structural system to meet the requirements for sealing and for support.
In the case of a plate and beam type door such an adaptation would consist
of a complete frame made up of angles or channels or a built-up section.
In the case of a reinforced concrete door some metallic elements would
have to be cast into and as an integral part of the door. For doors
fabricated from other materials similar arrangements will be required.

The simplest system by which sealing can be provided is shown
in Fig. 2.08. In this case the frame supporting the door is enlarged in
such a manner as to overlap the door opening. A solid or hollow seal
is placed around the complete door opening. The size of this seal will
depend on its distance from the door opening and the extent of the
deformation of the door under the positive phase. During the positive
phase of the blast any deformation of the door would tend to rotate the
door edges in such a manner as to destroy the sealing properties. In
addition, the seal must be of sufficient size to prevent its being
rendered ineffective during the negative phase. The extent to which this

is possible depends on the mechanical system used to provide support during this phase.

Although other materials may be developed for this application, it is suggested that the seal be made of a rubber, neoprene or a butyl to provide sufficient resiliency for increased sealing potential as the reaction on this material increases. In locations where cold weather can be expected, rubber should be used with caution since it may become brittle or lose its resiliency.

A seal provided in this manner can be attached to either the supporting structure or to the door by means of soft metal clips which will deform under relatively low pressure. The hinge supporting the door should also be designed as a flexible link so that it will be free to deform as the load is applied to the door and thereby cause the seal to become effective.

This system is by far the simplest and requires the least accuracy in the fabrication of the door itself. Relatively large inaccuracies in door dimensions can be tolerated. The system does, however, require that the proper attention be directed to support for the negative phase of the blast.

Another sealing mechanism is proposed in Fig. 2.09. As in the previous system the frame supporting the door is enlarged in such a manner as to overlap the door opening. In this case a T-shaped appendage is attached to the face of the door. This appendage is intended to function as the male part of the seal. The female portion of the seal is a cast gasket which is placed in a groove in the supporting structure around the periphery of the door opening. Somewhat greater accuracy will be required in the fabrication and installation of such a system; however, by sloping the sides of the T and of the groove in the cast gasket this unit can be designed in such a manner that the sealing potential will increase as load is applied to the door. It will be necessary for the cast gasket on the vertical side of the door nearest the hinge to have a groove of a different design in order to permit the T-section to make a proper entry when the door is closed.

Although this system requires somewhat greater accuracy than
that previously described it has the advantage of providing good sealing
characteristics during the negative phase. By a simple adjustment of
the depth of the T-section and the corresponding groove in the cast
gasket the expected deformation during rebound or the negative phase
can be taken into account.

Two additional systems are shown in Figs. 2.10 and 2.11. Both
of these systems require greater accuracy in both door dimensions and
supporting structure dimensions than the systems previously discussed.
In both cases the door is fabricated on the basis that it will enter the
door opening provided and the sealing characteristics are derived from
this fact. In Fig. 2.10 all sides of the door are tapered as are the
sides of the door opening. At the point where the door and the door
opening are in contact a neoprene, butyl or teflon gasket insert is
provided. As the load is applied to the door its deformation automatically
increases the sealing provided. It is obvious that this system will
require considerable accuracy in both the door dimensions and the dimen-
sions of the opening since a small discrepancy could destroy its useful-
ness. This system could be modified to require less accuracy in the
following manner. The door could be fabricated with square sides and
the door opening provided with tapered sides. By using a hard material,
for example teflon, on the edge of the door and a softer material on the
door opening, for example neoprene, it would be possible for the teflon
to deform the softer material on the door opening and provide an
excellent seal.

Fig. 2.11 is somewhat a modification of the system presented
in Fig. 2.10 which would require somewhat less accuracy in fabrication.
The system again provides sealing as a result of the wedging action
introduced when the load is applied to the door. In this case a tapered
piece of hardware is attached to the door along the edges. This tapered
piece comes into contact with a second tapered piece cast as an integral
part of the door opening. Either one or both of these tapered pieces
can be installed with a neoprene or butyl gasket attached to it. The
necessity for this latter item can only be determined on the basis of

the accuracy which can be required in the fabrication of the door and
in the construction of the door opening.

It must be remembered that this particular system could not
be used on the vertical side of the door nearest the hinge. On this
side of the door a system similar to that presented in Fig. 2.10 would
be required.

Although this latter system has many advantages over all of
the others presented it has one serious disadvantage which must be
considered. In this case the support for the door during the positive
phase of the loading is provided directly by the sections attached to
the door and the structural element cast into the door opening. There-
fore, the connection of these elements to their respective partners must
be sufficiently strong to resist these load intensities without failure.

(e) <u>Support and Rebound</u>. These two items are discussed
together because of the manner in which they are inter-related. For doors
which are mounted on the outside of the shelter the support for the
positive phase is provided by the bearing of the door on its supporting
surfaces. However, rebound and negative phase would require a separate
support system. This support system must be designed so that it will
not yield, since any yielding would probably destroy the seal provided.

For the positive phase the only requirement is that the struc-
ture surrounding the door be designed and reinforced to resist the
maximum load which the door can resist. This requirement would most
certainly result in an increase in the amount of reinforcement in this
region and might possibly require an increase in the thickness of the
concrete in this area.

In order to provide for the rebound or the negative phase the
supporting mechanism should be designed for one-half (1/2) the peak
pressure during the positive phase. As mentioned above, support for
this type of loading must be provided separately. Such a support
system can be most easily provided by a system of dogs or bolts or
pins. The simplest system which would involve the least cost and the
least accuracy in fabrication would be a system of dogs similar to those
shown in Fig. 2.12. These dogs provide a wedging action and, as such,

pull the door into position to provide sealing during both the positive and negative phase of the loading.

The next system which might be employed, in order of increasing accuracy required, would be a system of bolts. In the cases where the door does not extend to the inside face of the supporting structure it is necessary to provide a suitable extension in order that the bolt will slide and bear on the inside face of the supporting structure.

A pin, as used herein, is simply a bolt which extends into a hole provided in the supporting structure. Such a system necessarily requires greater accuracy in alignment of the door and the supporting structure in order to insure that the pins will meet the holes provided with a minimum of tolerance. The tolerance must be kept to a minimum because of the necessity of providing for adequate sealing during the negative phase.

The systems enumerated above can be activated singly or as a unit. An automatic system similar to that provided on a safe door could be provided in such a manner that all units became engaged simultaneously. Such a system would, of course, add to the cost of the door mechanism in proportion to the accuracy required.

For any of the items mentioned above not less than six such dogs or pins should be provided for any one door. These should be distributed in such a manner as to provide two along each long dimension of the door and one along the short dimension of the door. It would be preferable if the supports are placed not more than 2 ft. center to center in order to preclude a local breakdown in the sealing provided.

For the case in which the door swings into the shelter area the problem is complicated only to the extent that such mechanical systems must provide for the positive phase. For this reason their design and operation would be more critical and a foolproof system would be required. Under such circumstances it would probably be preferable to provide a system whereby a single operation would engage all of the dogs or pins. The total capacity of the dogs or pins provided should be such that they would not yield at a load equivalent to the yield capacity of the door provided.

(f) _Door Design._ There is no particular distinction
between the two types of support except for those mentioned in connection
with the systems necessary for support. No particular difficulty is
anticipated for this item, but strengthening features around the
pin locations or the dogs will probably be required.

(g) _Psychological Aspects._ Some parts of this problem
have already been discussed in connection with safety and those mentioned
above are certainly the most prominent. The only other problem from this
standpoint is in connection with the requirements for opening the door
when exit from the shelter is possible. In the case where the door
swings into the shelter there is no difficulty. However, for the case
in which the door swings into the entrance corridor the possibility
of jamming the door by people trying to enter the shelter is increased.

3) _Sliding Doors._ This particular system of door closure is
more difficult to evaluate because it has such distinct advantages as
well as disadvantages. The use of this type of door closure would be
dependent primarily on the extent of maintenance during extended periods
of inactivity.

(a) _Cost._ The initial cost of mechanical systems for
this type of door may be very slightly higher than for the other systems.
However, this difference in cost will in many respects be outweighed by
other considerations. In terms of cost of the door itself there would
be little, if any, difference between this type of door and the hinged
type.

(b) _Safety._ Consideration of this item indicates that
the horizontal sliding door has distinct advantages over the vertical
sliding door. The horizontal sliding door would be somewhat slower
in its response to the signal to close unless some mechanical system
was installed. Doors designed for the pressures considered in this report
would not be extremely heavy and, if provided with a sufficient number
of rollers, the movement of horizontal sliding doors should provide no
difficulty. The vertical sliding door, on the other hand, although
positive in its response to gravity would be considerably more dangerous
and would require some buffing system at floor level.

(c) <u>Sealing</u>. This item requires that we distinguish between doors which slide on the inside or on the outside of the shelter. For doors which slide on the outside of the actual shelter entrance sealing for the positive phase can be accomplished by a passive system of relatively simple design. Provision for adequate sealing during rebound or during the negative phase would require an active system as well as consideration of the magnitude of these two items.

In the case where the doors slide inside the shelter, active sealing would be required for the positive phase while the rebound and negative phase would be adequately provided for by the passive sealing provided by the same system used previously. Since active sealing mechanisms are not easy to design and are subject to considerable difficulty in operation it is more reasonable to provide some system whereby sealing can be accomplished in all cases by passive systems.

Because of the deformations expected to occur in the structural system of the door and because of the dependence of the sliding operation on the geometrical configuration of the door it is necessary that consideration be directed first to the problem of guaranteeing the sliding action even after severe damage to the door. This is most readily accomplished by framing the door in the manner shown in Fig. 2.13. In this diagram we have shown the structural door framed within an assembly of channels. The size of these channels is chosen so that the dimension "d" is greater than the maximum deformation expected to occur in the door. Even if this deformation should occur the door would still be operable since all clearances provided will be such that they will be able to accommodate the dimension "d".

The location of the sliding door may vary and three likely locations are shown in Figs. 2.14, 2.15 and 2.16. If there is a turn within the entrance tunnel, the location shown in Fig. 2.14 has several advantages. It is out of the way and does not interfere with any other operations. It also may enlarge the capacity of the shelter by providing protection within the corridor itself. The mechanical systems important

to its operation are easily accessible and therefore can easily be
examined and maintenance operations carried out with a minimum of
effort. Finally, part of the support is provided by the corridor wall
and only one auxiliary column is required.

The location shown in Fig. 2.15 has the advantage of providing
a layout whereby the sealing operation is easily accommodated by passive
systems for both the positive and negative phases. This system has a
number of very serious disadvantages which restricts its use to those
situations in which no other system is appropriate. First, maintenance
is extremely difficult, if not impossible since the door is stored in
a slot provided between the corridor wall and the shelter wall.
Secondly, and very important, is that this appendage to the entrance
tunnel provided for storage of the door presents serious problems with
respect to its design. Finally, there is the problem that in the event
debris gets into the channel in which the door rides or in the cavity
in which it is stored it may be impossible to open it when exit from
the shelter becomes possible.

The final location to be considered is actually in the shelter.
This system is very similar to the system shown in Fig. 2.14 in that all
of the mechanism is quite accessible. However, as shown in Fig. 2.16, this
particular arrangement requires two columns for support during the
positive phase. It is preferable that these columns be such that this
load is not transmitted to the shelter itself.

As mentioned earlier in this discussion active seals are
difficult to provide and somewhat uncertain in their operation.
Consideration must therefore be given to means for providing passive
seals to accomplish the necessary isolation of the shelter. For the
case shown in Fig. 2.15 it has been pointed out that this is taken care
of automatically and seals of the type shown in Fig. 2.08 will suffice.

It is necessary to add some additional mechanical system to
the doors in the case of the configuration shown in Figs. 2.14 and 2.16.
A relatively simple and inexpensive system whereby this can be accomplished
is sketched in Fig. 2.17. In this system the main structural door is
attached to a frame of channels which in turn is connected through a

series of elongated slots to a second frame of channels. The door can
now be moved in such a manner that it is forced into position with one
channel frame compressing a passive seal against one face and the other
channel frame compressing a second set of passive seals against the other
supporting face.

Movement of these channel frames can be accomplished in any
of several ways. A series of screw jacks provided around the perimeter
would permit the channel frames to be extended until adequate sealing
had been provided. This particular system would be a little slow. A
better method would be to provide a wedge in the form of a cam which
when rotated approximately 90 degrees would force the door into position.
The final system, which is the most desirable, but also the most
expensive, incorporates a pre-pressurized hydraulic or gas operated
system connected to a set of jacks around the perimeter of the door.
Such a system would have four distinct advantages. First, it would be
quick acting and would require movement of a single valve in order to
actuate the system. Second, the pressure within the system would be
capable of correcting for any deformation which might occur in the
primary supporting structure provided it is not excessive. Third, an
auxiliary hand operated system could be incorporated to permit operation
of the system in the event of a loss of pressure. Finally, pressure
within the system could be removed by bleeding off some of the gas or
hydraulic fluid. This system therefore incorporates all of the most
desirable features of a sealing system.

(d) Support and Rebound. It has already been shown how
the support system could be provided. For the case shown in Fig. 2.15,
conventional procedures of designing for blast loading would permit
calculation of the requirements for reinforcement needed.

In the cases shown in Figs. 2.14 and 2.16 it is also relatively
easy to provide support and conventional procedures can be used. However,
in these cases it is necessary to design the supporting columns for the
positive phase in such a manner that little, if any, plastic deformation
results. This requirement must be reviewed in the light of the system
provided for the proper operation of the seal.

(e) <u>Door Design</u>. Sliding doors offer some advantage over the hinged doors since they are supported on all four edges. However, in view of the extremely light construction required for the pressure levels being considered it is doubtful that this particular item would provide a substantial saving in cost.

(f) <u>Psychological Aspects</u>. The primary advantage of the sliding door system is that the entrance tunnel is completely unobstructed by any part of the door itself or by any hardware associated with its operation.

2.06 OPERATION CONCEPT

As has been previously discussed, many factors other than technical design considerations affect the selection of an entrance system. Some of these are psychological, while others have to do solely with the operation of the shelter itself. One of the factors that must be considered is the actual opening and closing of the shelter door or doors. Who, when and how? The answer to the first must rest with the preoccupancy planning. The answer to the other two are not as simple.

In the first place it is unreasonable to expect that all or even a large percentage of the shelter occupants will arrive at the same time. The question "Should the door be opened and thereby endanger all who already are in the shelter?" must be answered. The only means by which those already in the shelter can be protected when the door is opened if by the incorporation of a double-door interlock system, in which only one door is opened during the imminent danger period. The major disadvantages are that the interlock system will slow down the ingress rate when one door is closed and that the cost will be increased. Such an interlock system could have one exterior surface door and an interior corridor door, or have two interior corridor doors with the corridor element between. There is no analytical means of deciding whether or not to incorporate an interlock system. It must be resolved solely by weighing the advantages and disadvantages for a particular case.

One of the other problems related to the entrance system is the means, manual or mechanical, by which the door is closed. Under some circumstances, such as with a heavy door, there can be no question but that a mechanism must be used to close the door. It may be a simple jack or a lever or a block and tackle, but it is still a means of obtaining mechanical advantage. In general any such mechanism will tend to slow the closing and opening operation. It has the additional disadvantages that the mechanism must be maintained in operable condition and that the person operating the door may or may not be able to retain direct control.

Manual operation has the advantage of simplicity of details and better operator control.
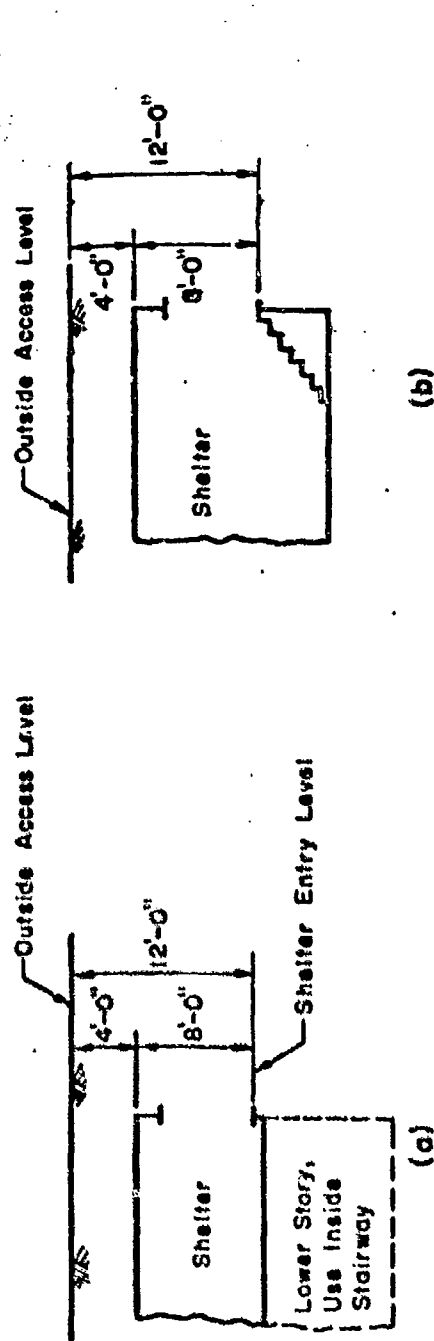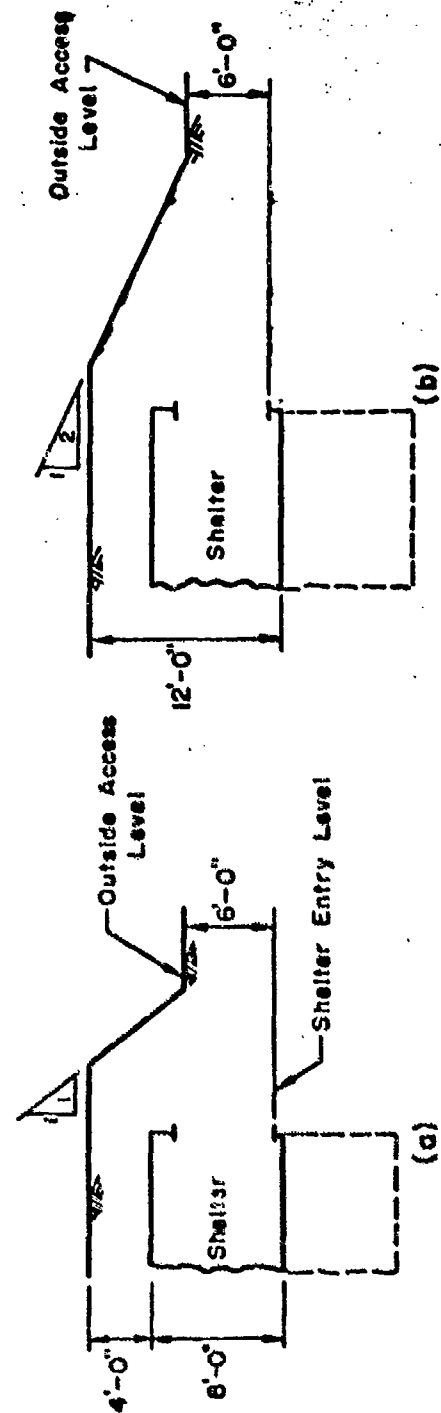
FIG. 2.01   IDEALIZED SITE CONDITIONS, CASE I AND II

Outside Acces Level

Shelter Entry Level

Shelter

12'-0"

4'-0"

(a)

Shelter

(b)

Building Wall

Case III

Shelter

12'-0"

4'-0"
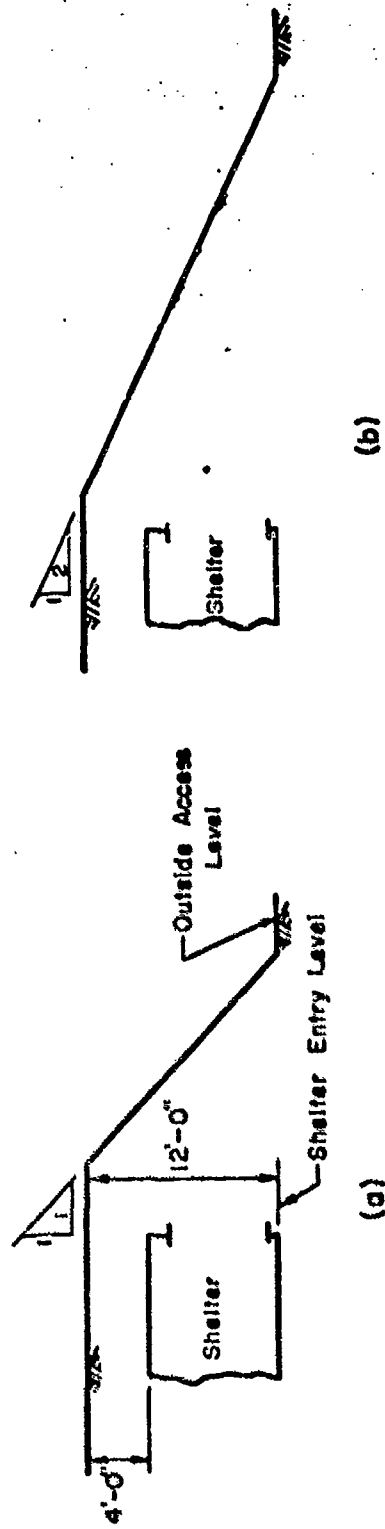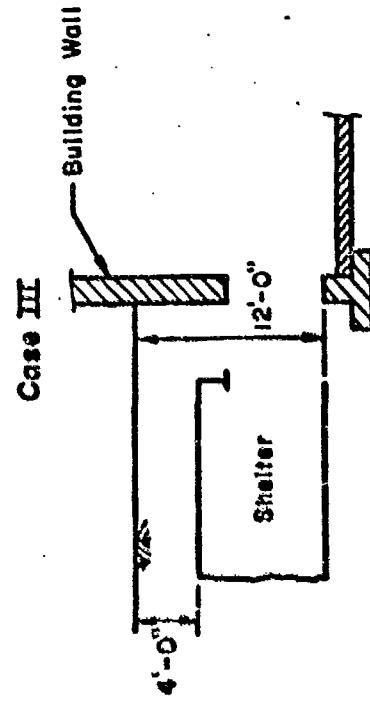
Case IV

FIG. 2.02   IDEALIZED SITE CONDITIONS, CASE III AND IV

Length of Door = 64'±

12'-0"

Shelter

1:10 Ramp

(a) With 1:10 Ramp

Door = 8'

Tread = 9½"
Riser = 7½"

Shelter

(b) Stairway

12'-0"

Shelter   Corridor
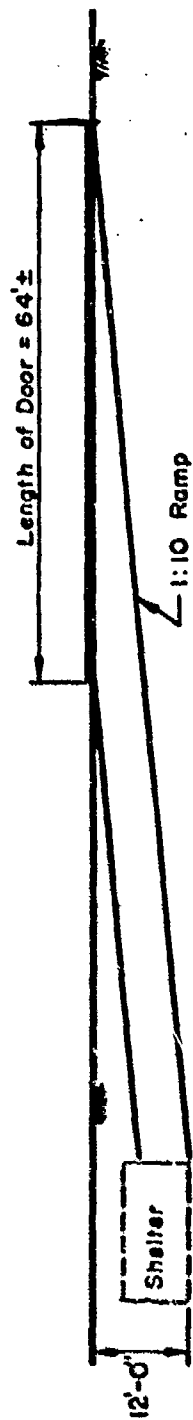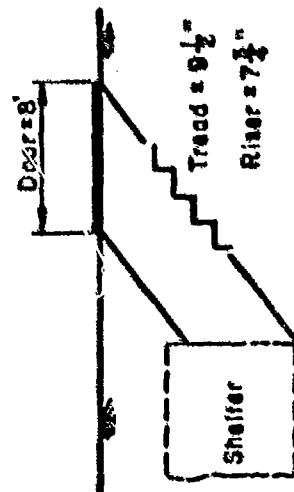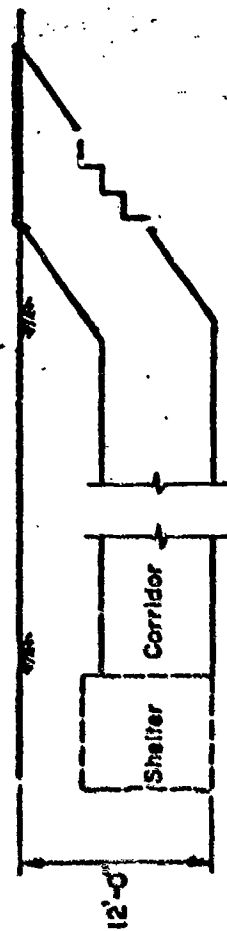
(c) Stairway With Corridor

FIG. 2.03 TYPICAL RISER ELEMENTS, CASE I
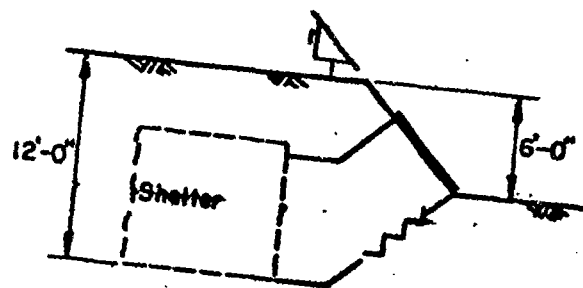
(a) With Stairway And 1:1 Soil Slope
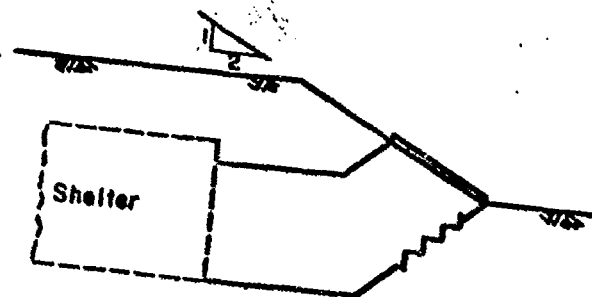
(b) With Stairway And 2:1 Soil Slope
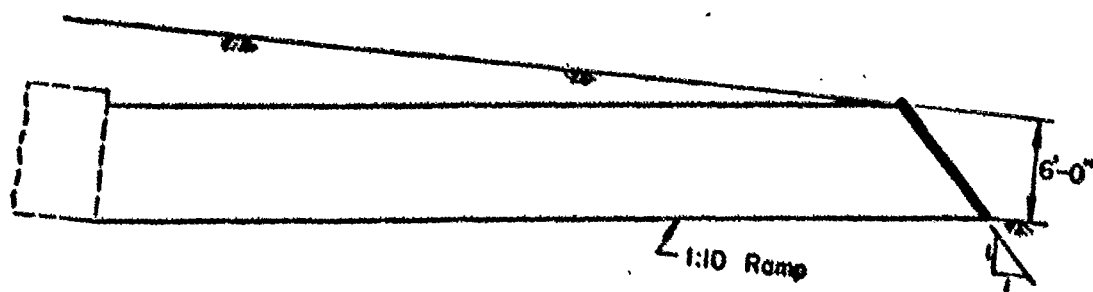
(c) With 1:10 Ramp And 1:1 Soil Slope
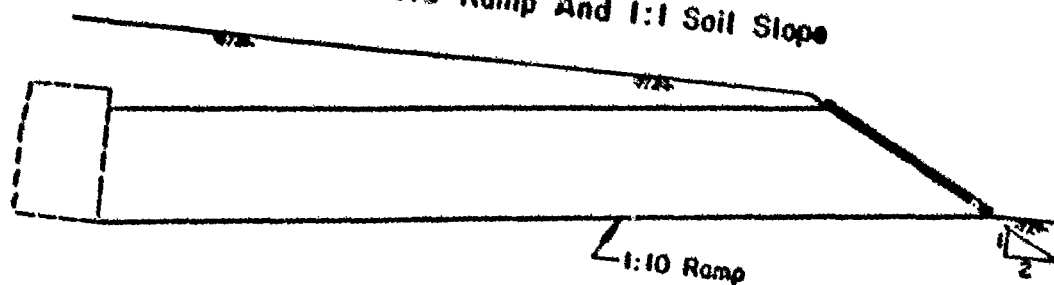
(d) With 1:10 Ramp And 2:1 Soil Slope

FIG. 2.04 TYPICAL RISER ELEMENTS, CASE II
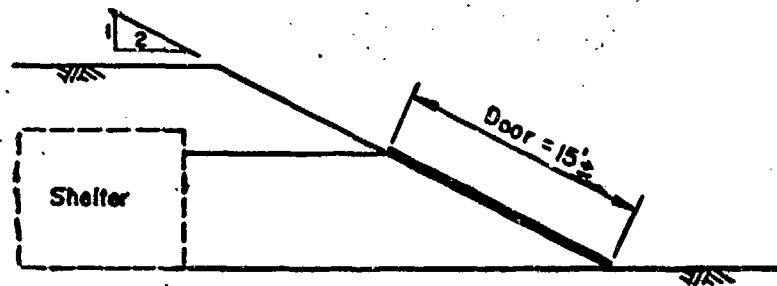
(a) 2:1 Soil Slope
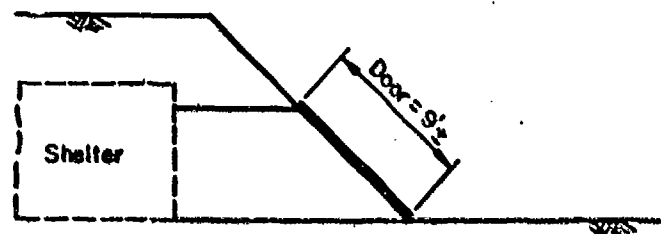
(b) 1:1 Soil Slope

FIG. 2.05 ENTRY CORRIDOR, CASE III
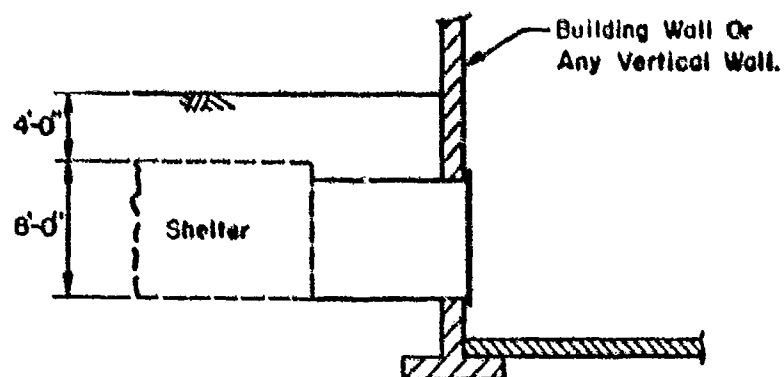
FIG. 2.06 ENTRY CORRIDOR, CASE IV

Ramp Of Metal Plate
Or Timber Construction.

Piano Type Hinge With Teflon
Or Similar Bearing Materials
To Prevent Corrosion.

Approximate
Slope Of 1:8

Upper Floor
Level

Lower Floor Level
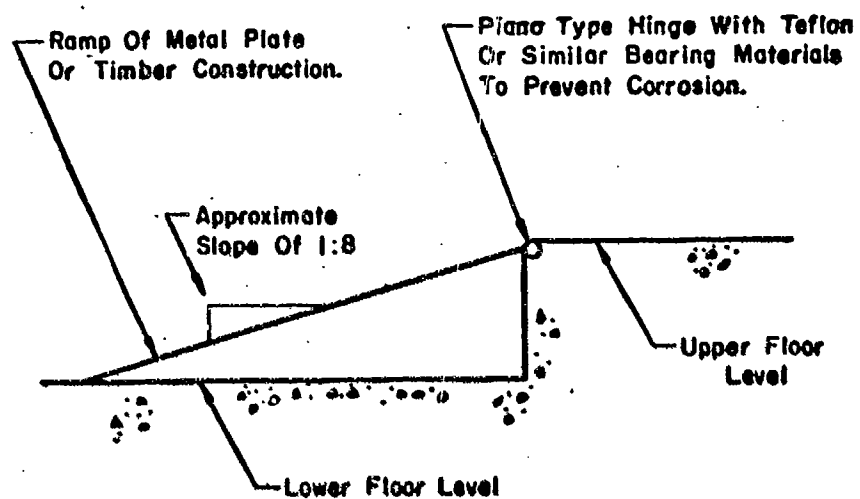
FIG. 2.07 RAMP FOR CHANGE IN FLOOR LEVEL

Door Opening

Door

Gasket

A

A

Gasket

Blast Door

Door Frame

Hinge

Support
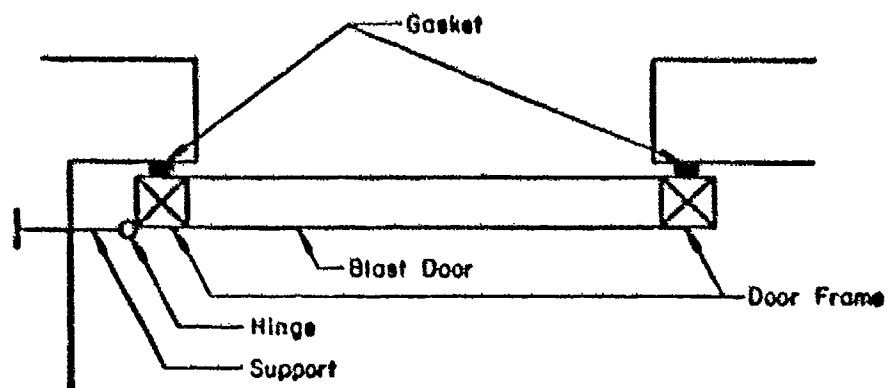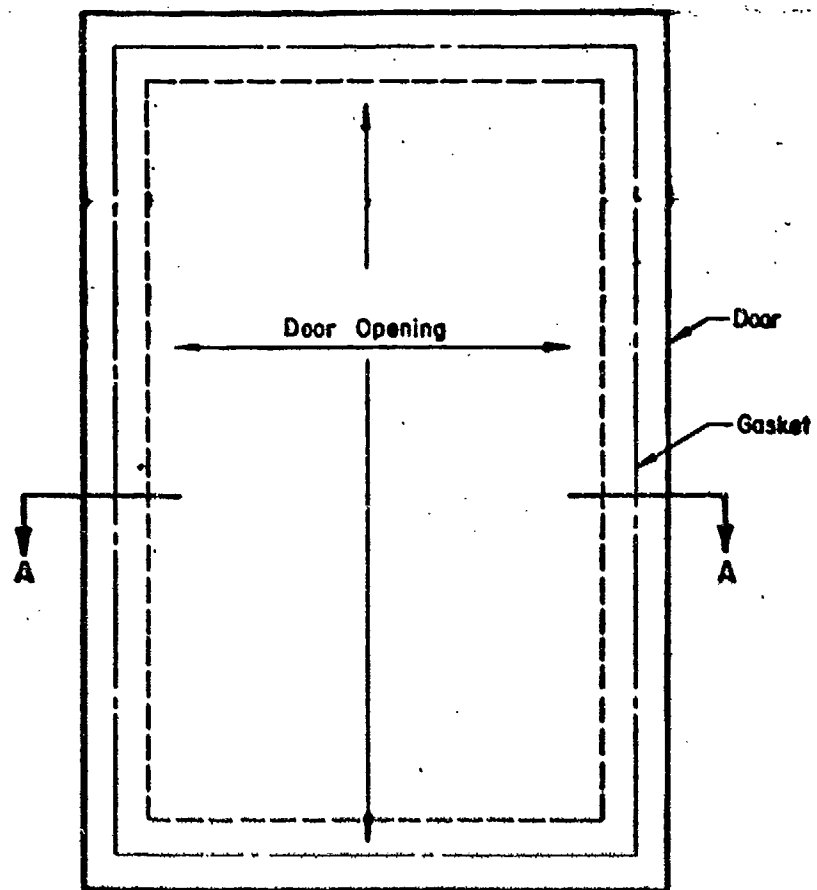
Section A-A

FIG. 2.08 PASSIVE DOOR SEAL

Door Opening

A

A

Door

Gasket

Gasket

T-Section
Attached To
Door.

Blast Door

Door Frame

Hinge

Support
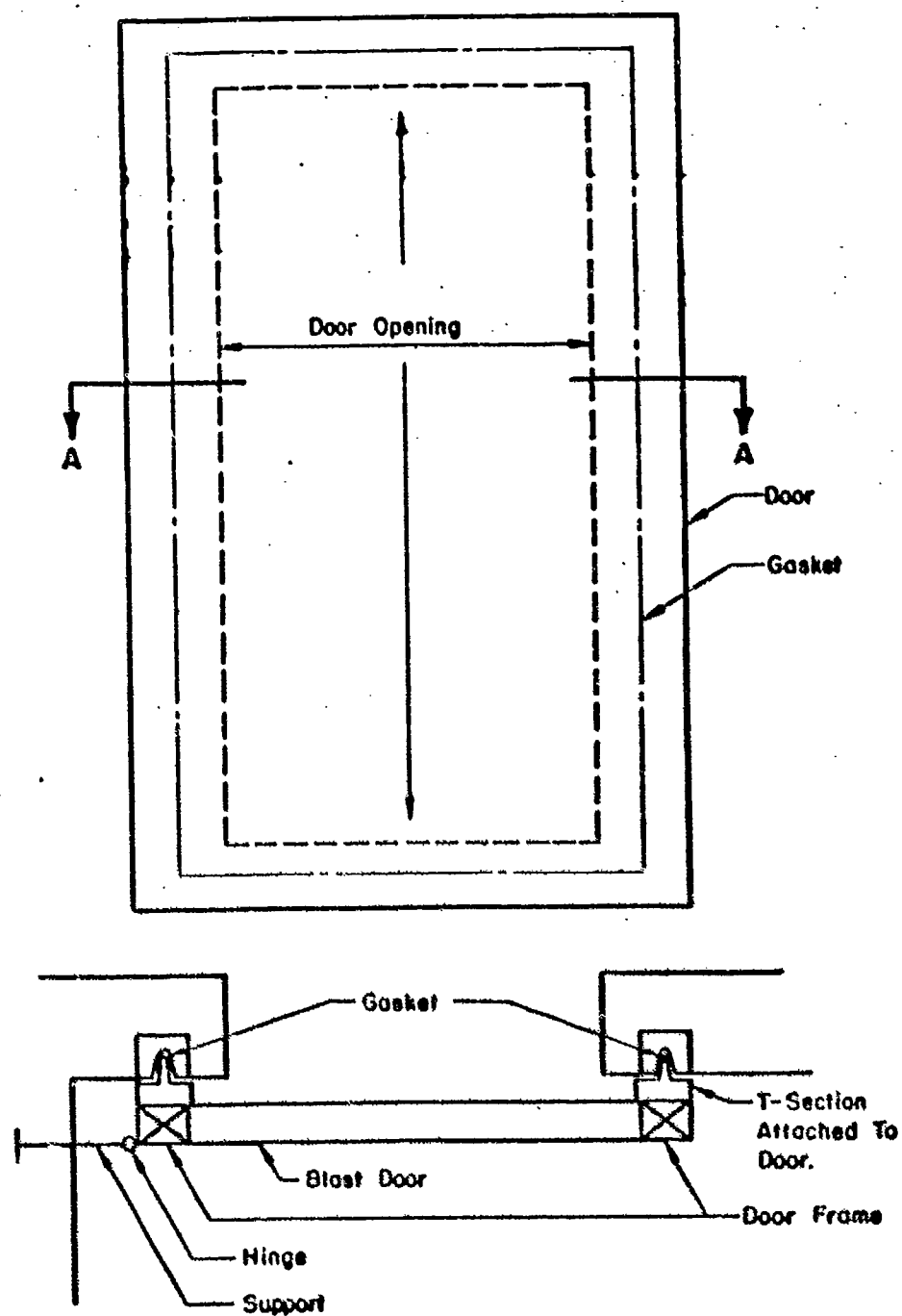
Section A-A

FIG. 2.09   PASSIVE DOOR SEAL

Door Opening

A   A

Gasket Inserts

Blast Door

Hinge

Support
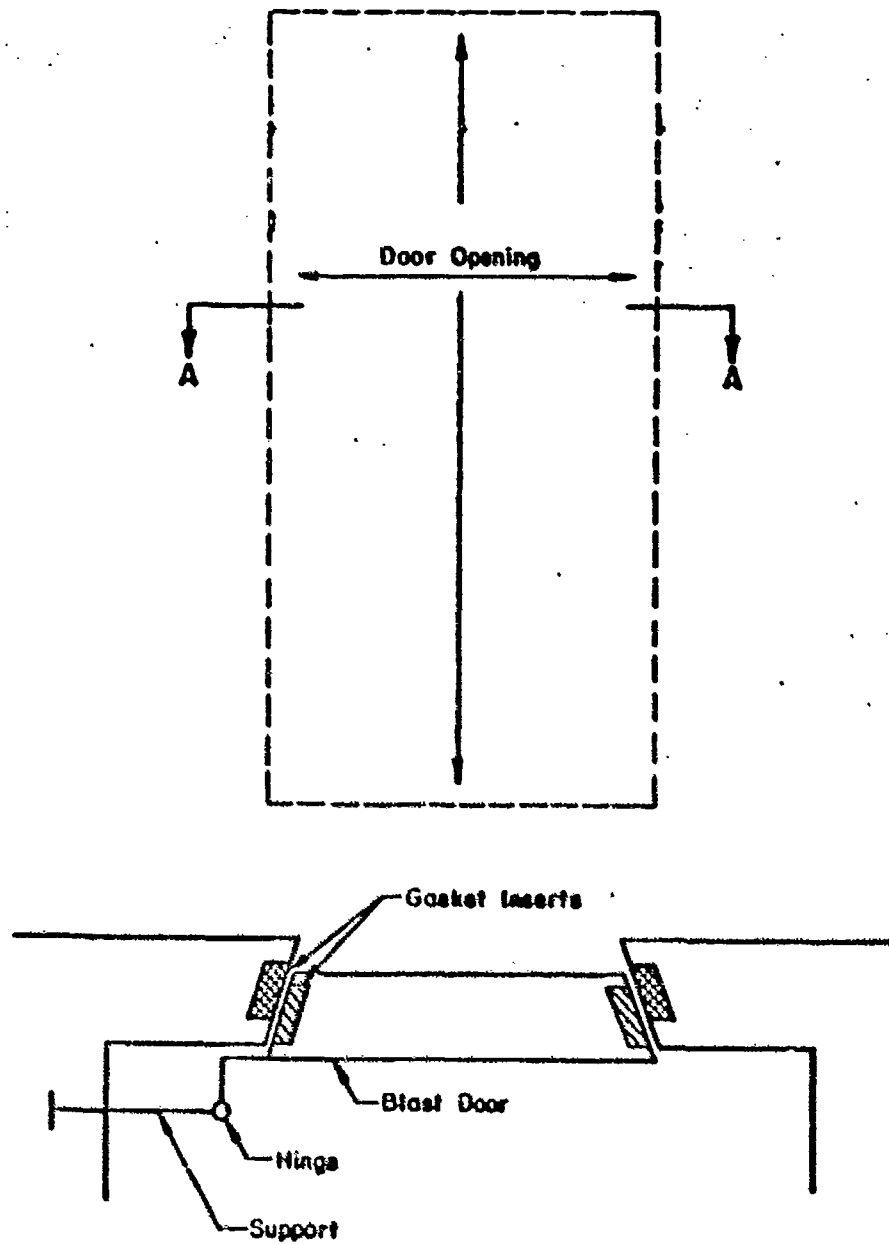
Section A-A

FIG. 2.10 PASSIVE DOOR SEAL

Door Opening

Channel

Frame

Gasket

Angle Attached
To Door

Blast Door

Section B-B

Frame

Channel

Entrance Tunnel
Floor

Neoprene Or
Butyl Gasket

Angle Attached To Door

Channel Cast
in Wall

Frame

Blast Door
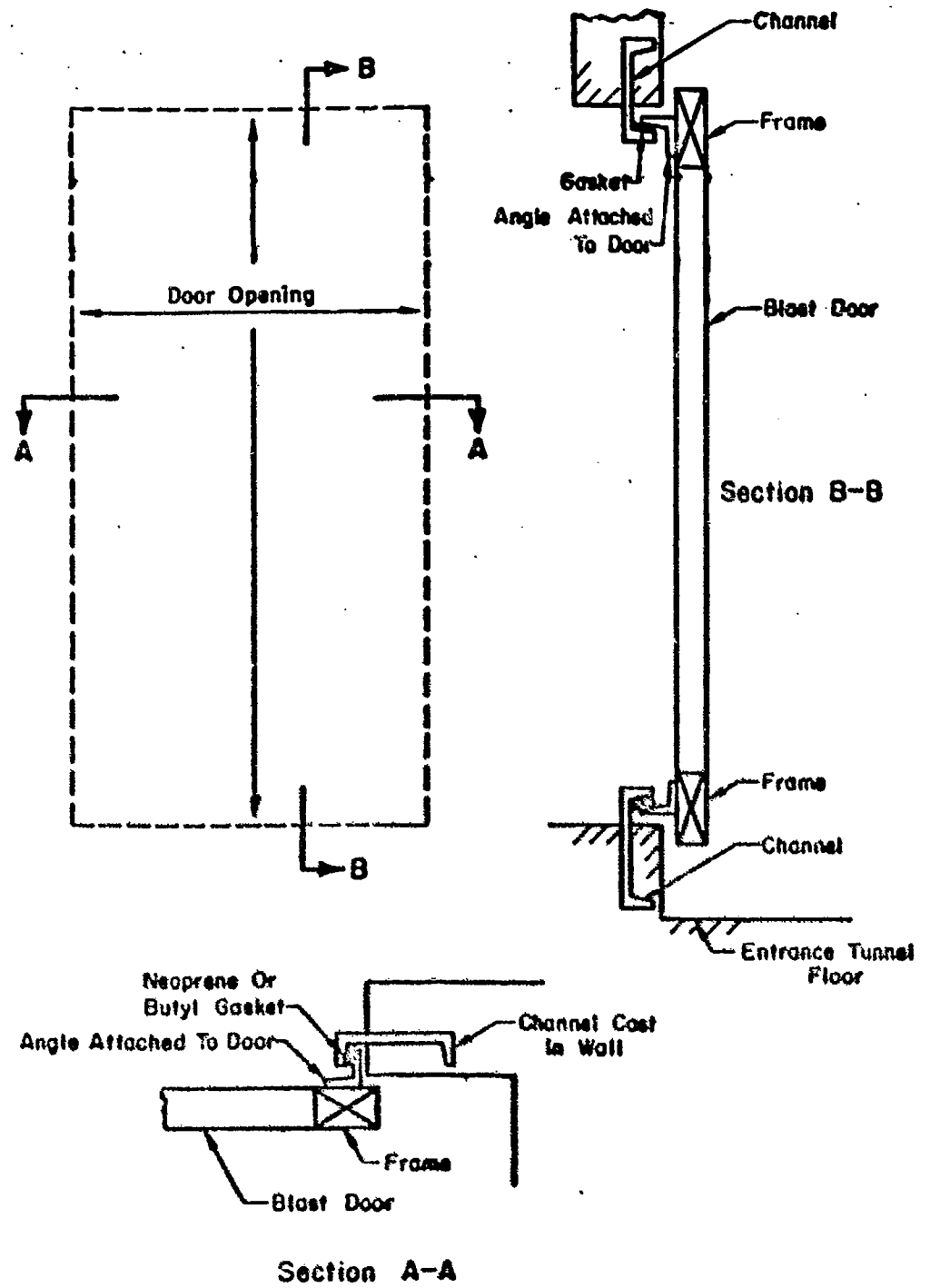
Section A-A

FIG. 2.11 PASSIVE DOOR SEAL, TYPE 0
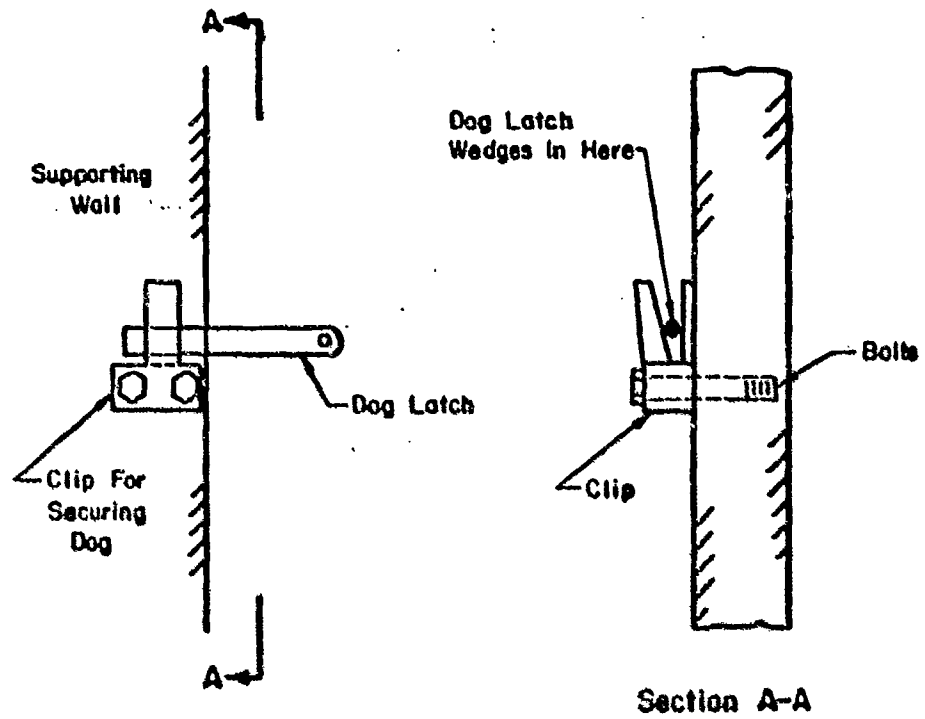
FIG. 2.12 SIMPLE DOG LATCH

Blast Door

Frame

A ← → A

Channel Frame

Blast Door
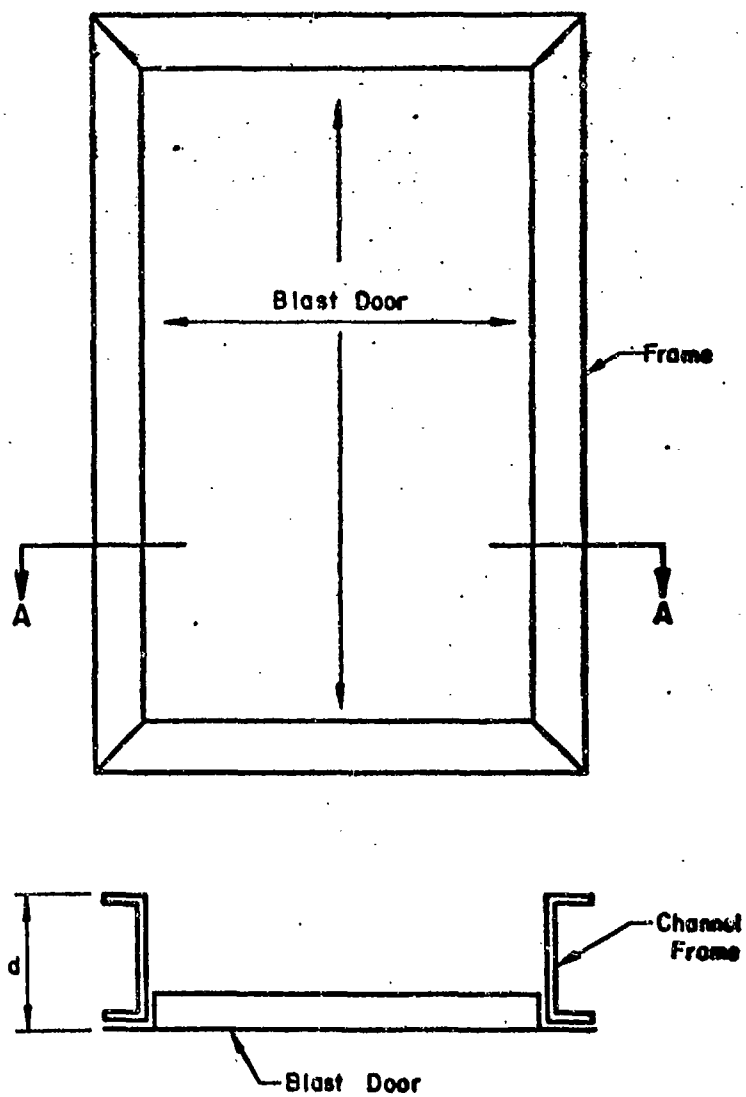
Section A-A

FIG. 2.13 FRAME FOR SLIDING DOOR

Sliding Door

Column

Entrance Tunnel Walls
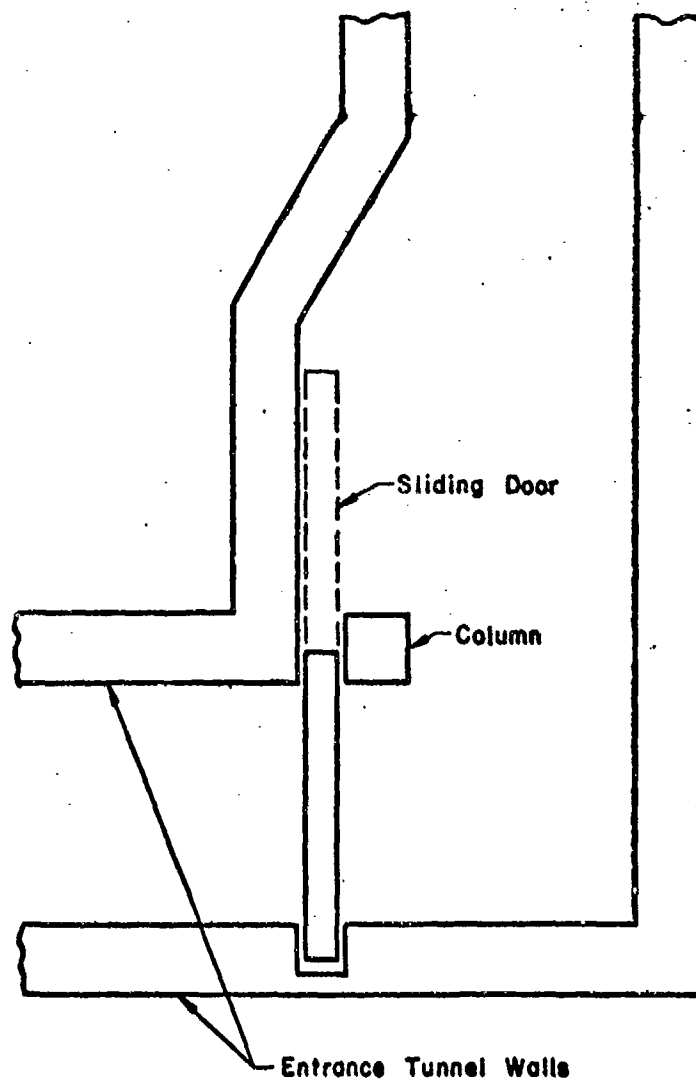
FIG. 2.14 SLIDING DOOR CONFIGURATION IN ENTRANCE CORRIDOR
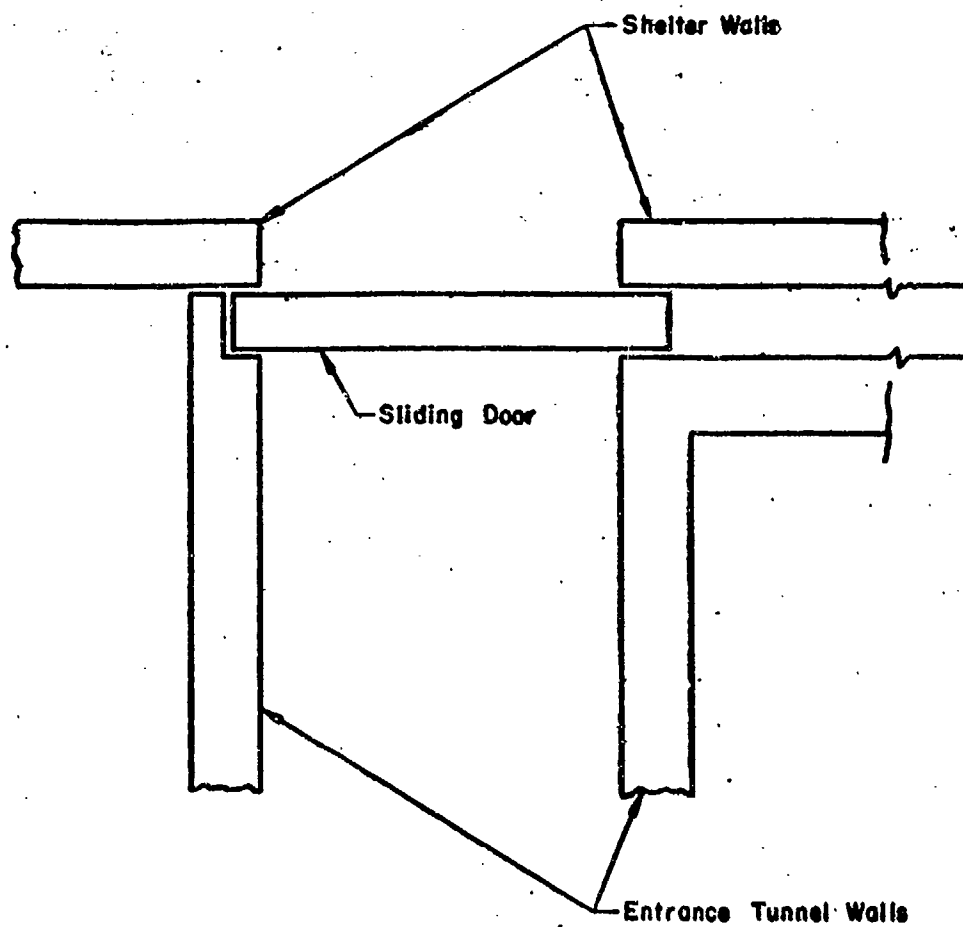
FIG. 2.15 SLIDING DOOR CONFIGURATION ON OUTSIDE OF SHELTER
AT END OF ENTRANCE CORRIDOR

66

Columns

Sliding
Door

Shelter Walls

Entrance Tunnel Walls
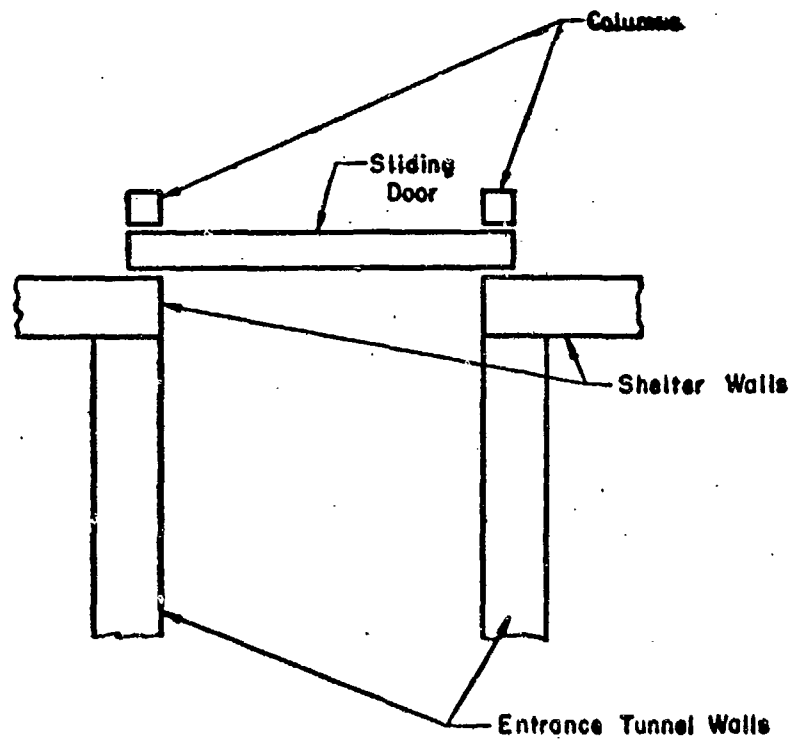
FIG. 2.16 SLIDING DOOR CONFIGURATION FOR DOOR INSIDE SHELTER
AT END OF ENTRANCE CORRIDOR

Column

Column

Gasket —— Jacking Mechanism —— Gasket

Channel

Channel

A

A

Door

—— Entrance Tunnel
Walls

—— Slotted Hole

—— Hydraulic Or Gas Operated Piston.
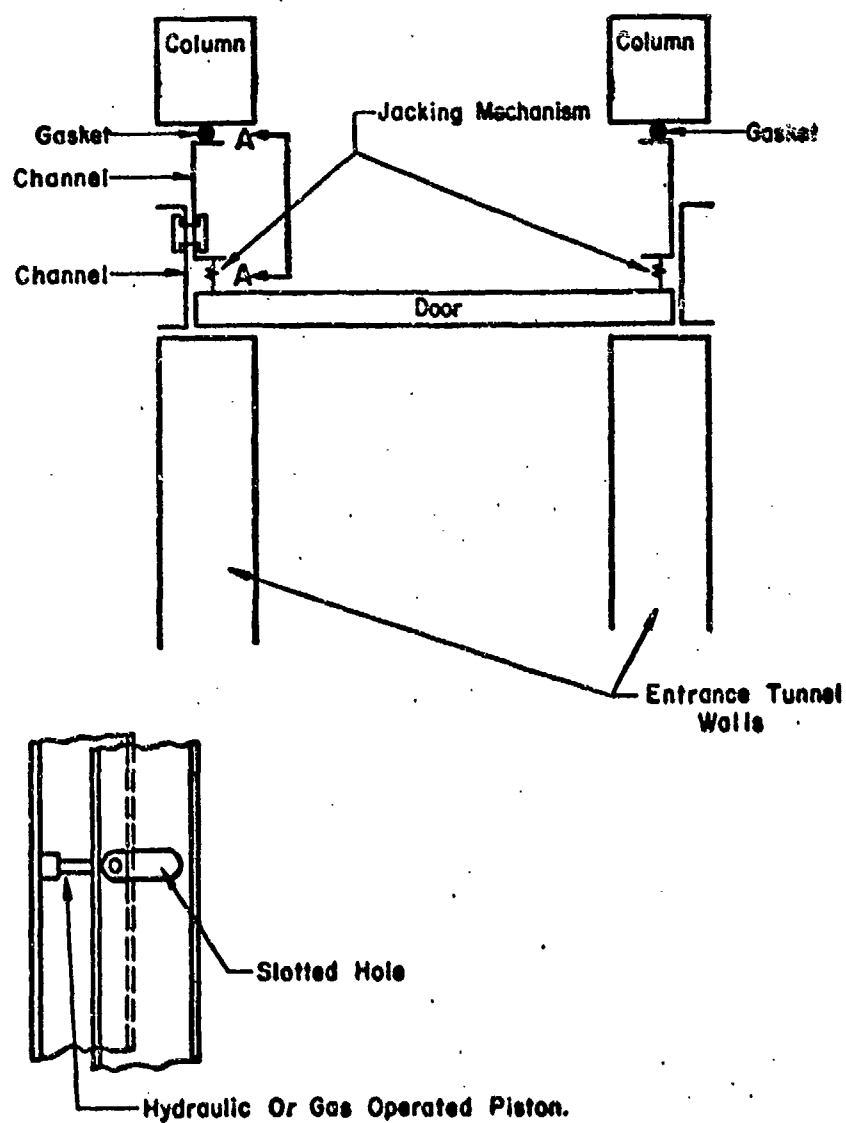
Section A-A

FIG. 2.17 MECHANISM FOR ACTIVATING SEALS ON SLIDING DOOR

CHAPTER 3. DIMENSIONS AND GEOMETRY OF ENTRANCE SYSTEMS

3.01 INTRODUCTION

In this chapter, the dimensions of entrance elements and the combination of these elements into possible geometries or systems are discussed primarily from the point of view of traffic safety and of their relationship to traffic flow. The effect of these dimensions and geometries on blast loading and radiation levels is discussed in Chapters 5 and 6.

3.02 DIMENSIONS OF ENTRANCE SYSTEM ELEMENTS

As stated previously, the criteria used in the selection of recommended dimensions are maximum traffic safety and flow under conditions of emotional stress conducive to accidents or panic. Since shelter experience is not available, at least in terms that are immediately applicable, the dimensions are derived from the comparable conditions which dictate the design of exits from places of assembly, taking into consideration the differences in traffic direction discussed in Chapter 2.

The dimensions and restrictions recommended below have been standardized over the past fifty years and thus comply with all building codes. However, in order to reconcile the small variances existing between local ordinances the model code published by the National Fire Protection Association (Ref. 3.01) has been used as a guide.

In this model code, the basic concept governing the width of exit elements, i.e., doorways, corridors, stairs and ramps, is termed the unit of exit. It is fixed at 22 in. and defined as the space necessary for the free passage of one file of persons. Exit elements are then described in terms of number of units, e.g., one-unit doorway, two-unit hallway, etc. Additional fractions of unit are considered useless except that an increment of 12 in. is rated as a half-unit because it increases flow capacity by permitting an intermediate staggered file; e.g., a 34 in. wide opening becomes a one-and-a-half unit doorway. Since the unit of width concept is based on the minimum dimensions allowing free traffic flow, it is applicable to either exit or entry. It is recommended, therefore, that it be used in the design of shelter entrances and has been so used in this study.

The following recommended dimensions and details have been incorporated in the example design included in Chapter 9.

1) _Doorways_. The minimum width is the unit of width, i.e., 22 in., measured in the clear except that total projection for jamb does not exceed 2 in. and, for rails at waist height, 3 1/2 in., thus reducing minimum unobstructed width to 20 and 18 1/2 in. respectively, the maximum allowable width of single leaf door is 44 in. The minimum headroom is 6 ft. 6 in. In all exit codes the swing of the door is specified to be in the direction of the traffic which, for exit systems, is outward, in order to prevent obstruction and casualties. For shelter systems, the flow of emergency traffic, conducive to panic or casualties, if undue restriction occurs, is inward. Everything being equal therefore and on the basis of past emergency experience, the door should be designed to swing inward, since exit from the shelter is not likely to demand maximum traffic flow. However, the swing of the door entails structural problems in connection with the blast loading, the response of the door and the jamb or frame details. Provisions for shelter management will also affect the ultimate direction and system of closure. These factors are discussed in other chapters.

2) _Corridors_. The unit-of-width concept is applicable for corridors, except that the minimum allowable width is 30 in. Total restriction of 2 in. for jambs and 3 1/2 in. for rails at waist height are allowed, thus reducing minimum clear width to 28 in. and 26 1/2 in. in the clear. One waist-high handrail must be provided per unit of width. It is recommended that the minimum unobstructed headroom be 7 ft.-0 in. for corridors of two-units or less and for 8 ft.-0 in. corridors wider than two-units.

3) _Ramps_. Allowable width, headroom and handrail specified for hallways are applicable to ramps. The maximum allowable slope is 10 percent (1' in 10').

4) _Stairs_. The unit-of-width concept is applicable for stairs except that the minimum allowable width for a single stair run between two solid walls is 30 in., and the minimum width for a double stair run

separated by a railing and housed in a single stairwell between solid walls is 48 in. Total rail projection is not to exceed 3 1/2 in. The depth of landings must not be less than the allowable width of the stair run. Height between landings must not exceed 8 ft.-6 in.

Local codes regarding allowable dimensions of risers and runs (treads less nosings) are by no means uniform but the variances are not significant. A maximum riser height of 7 3/4 in. and a minimum run of 9 1/2 in. plus 1 1/2 in. nosing is recommended. It must be emphasized, however, that good design practice tends toward a slope less steep than the maximum allowable, that the stairs are the most critical element of the entrance system from a traffic point of view, and that the extra cost to obtain maximum traffic safety is trivial.

5) Summary. The dimensions of the entrance system elements are summarized in Table 3.01

3.03 ENTRANCE TRAFFIC RATES

1) General. The traffic capacity of the 22 in. unit width recommended in the codes of the National Fire Protection Association are given as 60 persons per minute per unit for a level doorway or hallway and as 45 persons per minute per unit for a descending stairway. These rates are stated to correspond to an evacuation time of 1 minute 40 seconds, exclusive of the time necessary for the first person to reach the doorway and for the last person to reach safety. Accordingly, for an exit system composed of horizontal elements and a stairway, the latter rate controls the rate of the total system. A balanced system therefore requires at least a 1 unit doorway with a 1 1/2 unit stairway or, better still, a 1 1/2 unit doorway with a 2 unit stairway. The same proportions apply to ramps whose slope are 10 percent or steeper.

All the available data relevant to personnel traffic on which these codes are presumably based were reviewed and analyzed in a study of military shelters by Armour Research Foundation (Ref. 3.02). The amount of data is not large and consists of measurements of many different conditions including fire drills in schools, sidewalk and cross street traffic,

rush hour flow at railroad and subway stations, stadium crowds, ad hoc
studies of stairs, ramps and hallways, etc. The test procedures also
vary widely and all the factors affecting the results are not adequately
reported so that the derived traffic rates by no means express the full
potential capacity of each type of passageway under conditions of traffic
stimulated by the approach of danger. Nevertheless, once reduced to
comparable criteria the data are fairly consistent, without undue scatter,
and very likely quite representative of the random character of undisciplined
civilian traffic and of the unpredictable conditions which may exist at
alert time.

Purely qualitative and daily observations, wherever concentrated
traffic occurs, show that traffic rates are directly dependent on both
velocity of motion and density of traffic. Maximum flow occurs at
relatively low density where each person is separated in the direction
of motion by at least the length of a full step and at relatively low
velocity. Whenever the objective of the traffic tests included velocity
and density measurements, the results quantitatively confirm the random
observations.

2) Stairs. Considering first the problem of descending stairway
traffic, which in most cases will control the overall rate of shelter
entry, past tests show average flow rates ranging from 20 to 53 persons/unit
width/minute and a mean rate of 32. Peak rates have been measured at 62
and corresponding velocities range from 1.32 to 2.2 mph. More accurate
and meaningful tests have been conducted in Paris and London. Using fire-
men as subjects, the Paris Fire Brigade measured traffic rates on descending
stairs of 51 persons/21 in. unit width/minute for normal walking pace and
of 73 for hurried pace without pushing. These rates, obtained with trained
and disciplined men, correspond to optimum density of about 8 sq. ft./
person and velocity of about 3 mph. The London Transport Authority has
conducted a number of tests and published suggested traffic rates for design
purposes of 38 persons per unit per minute with corresponding density of
6.5 sq.ft./person. Armour Research Foundation (Ref. 3.02) on the basis of
the Paris and London data computes a possible peak rate of 80 persons per
unit per minute for a velocity of 3.90 mph and a density of 8 sq.ft./person.

The traffic rates averaged from the data on stair descent are lower than
those recommended by the National Fire Protection Association (Ref. 3.01).
However, the peak rates based on higher velocity and more purposeful
traffic direction are much higher.

Considering the quality of the data and the design requirements,
an average rate of 40 persons and a peak rate of 60 persons/unit width/per
minute, corresponding to an optimum density of 6 to 8 square ft. per
person, has been used in the illustrative example of Chapter 9.

3) <u>Corridors</u>. With reference to traffic rates through level
corridors and doors, the most comparable and significant measured rates
are tabulated as follows (Ref. 3.02):

Observation	Persons/22 in. unit width/minute
Rochester, N.Y. fire drills	
Average rate	40
Peak rate	77
Railroad station rush hour	
One minute flow	38
British fire drills	
Average rate	47
Paris fire drills	
Normal walking pace	35
Hurried pace without pushing	48
Hurried pace with pushing	64
London Transport Authority (Boys Test)	
Average rate	40-50
Peak rate	70-90
London Transport Authority (passengers)	
Average rate	56
Peak rate	70

The Armour Research Foundation (Ref. 3.02) analysis of the above
data shows that peak rates occur at densities of 8 to 10 sq. ft. per person
and that average rates can be expected with densities up to 4 sq. ft. per
person. At higher densities, say 3 to 2.5 sq. ft. per person, the choke
point is reached and traffic stops. Peak rates correspond to 4-5 mph
velocities and average rates to 1.5 - 2 mph.

As in the case of stair traffic rates, the level rates derived
from actual measurements differ somewhat from the design rates specified
in the National Fire Protection Association codes (Ref. 3.01). The test
data suggest recommended average rates of 50 persons and peak rates of
70 persons/unit/minute. These rates bracket the code exit rates and are
consistent with observed differences between level and descending stair
traffic.

4) <u>Ramps</u>. The effect of sloping ramps on traffic is not pro-
nounced, nor are the measurements reliable. Expressing the descending
ramp rates as a percent of level traffic, Armour Research Foundation
(Ref. 3.02) estimates these rates as follows:

Level hallway	100%
5% ramp	99
10% ramp	97
12% ramp	93

These adjustment factors for ramps appear quite small and their
implied accuracy too fine to have any design significance. Ramp traffic
rates should therefore be considered as equal to level rates.

5) <u>NCEL Test</u>. A unique test of shelter entrance traffic vali-
dates the traffic rates discussed and recommended in the preceding
paragraphs. The test was conducted at the Naval Civil Engineering Laboratory,
Port Hueneme, California and used the standard Navy buried arch shelter.

The entrance of the Navy shelter is a 45° above-ground steel
hatch opening on a 24 in. wide stairway with a 45° slope (9 in. risers and
9 in. treads). The stairway opens straight into the shelter in the
direction of the long axis. Navy personnel were ordered to enter the shelter
at ordinary military pace, without hurrying and observing "orderly"
behavior. The men came from stations 100 ft. to 200 ft. distant and
converged on the entrance without producing any waiting queue or bunch at
the hatch door. The rate of entry was 40 men per minute. Photographic
records show an average spacing between men of somewhat more than 3 ft.
corresponding to a density of about 8 sq. ft. per man, and to a velocity
of about 1.75 mph. According to observers, a more hurried pace would have
been possible and would have resulted in a higher peak rate.

3.04 GEOMETRY OF ENTRANCE SYSTEMS

A number of system geometries are possible which variously combine the depth (stairway or ramp), landing, corridor, or door elements, that will provide a satisfactory solution to the set of restraints or requirements of a particular shelter. Such configurations will usually begin with a depth element leading from the ground surface to the level of or above the shelter, thence to a corridor to the shelter. These may take the basic form of a straight line, an angle, a "Z", or a "U" (Fig. 3.01) or a combination of any of these basic types (Figs. 3.02, 3.03, 3.04, and 3.05).

1) <u>General Considerations</u>. In determining the geometry of an entrance system, the following must be considered:

(a) In order to minimize the radiation contribution through an open stairwell, the stairwell should be as narrow as possible and as steep as possible consistent with building codes.

(b) In order to minimize the radiation contribution through the roof of the entrance system, it is necessary to descend to the level of the shelter proper as quickly as possible. A larger overhead mass thickness may be attained in a shorter time with a steeper stairway.

(c) In order to increase the radiation protection and to prevent the blast wave from re-forming as an ideal shock front, several alternating short lengths of corridor and 90° bends are desirable.

(d) Additional corridor length attenuates both prompt gamma and neutron radiation and residual gamma radiation. However, a length of straight corridor on the order of 5 to 10 corridor diameters will permit the blast wave to reconstitute itself.

(e) Turns and corridor lengths, while beneficial from the blast and radiation standpoint, require additional real estate, excavation, materials, etc.

(f) If entrance elements are oriented 90° or greater apart from one another, the possibility of a burst being directly in line with more than one opening is eliminated.

(g) Building codes requirements as to widths, risers and treads, heights of corridors, heights between landings, numbers of

exits, etc., must be considered.

2) Straight Line Entrance. A straight line entrance (Fig.
3.01) has the advantages of simple forming and construction and of being
particularly suited for a long, narrow site, e.g., under a highway.
However, in addition to the disadvantages of requiring an excessive
amount of real estate and long excavation, it affords relatively minor
blast and radiation protection. Further, it may have a psychological
drawback in that people entering the shelter are staring down a long
tunnel.

3) "U" Entrance. At the other end of the spectrum from
the straight line entrance is the "U" entrance (Fig. 3.01). Not only
does such an entrance configuration require much less space, thus
permitting its use in restricted areas and requiring much less excavation,
it provides the optimum in blast and radiation protection. The short
lengths of corridors and 90° bends provide excellent attenuation for
the radiation and prevent the blast wave from reconstituting. Likewise,
from a psychological standpoint, the lengths of the individual corridors
are relatively short and do not give the appearance of unending tunnels.

4) Angled and "Z" Entrance. Intermediate between the straight
line entrance and the "U" entrance are the angled entrance and the
"Z" entrance. These entrances require at least the same or possibly
more real estate than the straight entrance. Although they provide more
radiation and blast protection than the straight line entrance, they
in general will provide less radiation and blast protection than the
"U" entrance.

5) Combination of Basic Entrance Types. The capacity of an
individual shelter might require the combination of the basic entrance
types for one entranceway. For instance, for an entrance of several
unit widths, it may be desirable to use several smaller depth elements
feeding into a common corridor element. Likewise it might be desirable
to have a single depth element of several unit widths serving several
shelters by means of individual corridors after the depth element.

(a) <u>Multiple Depth Elements</u>. An example of multiple depth elements entering a common corridor leading to a single shelter is illustrated in Figs. 3.02 and 3.03. By separating the depth elements, congestion at the surface may be reduced. By orienting the depth elements 180°, the radiation contribution through the entranceway is reduced.

(b) <u>Multiple Shelters</u>. Examples of single entranceways serving multiple shelters are illustrated in Figs. 3.04 and 3.05. Such entrance configurations might be dictated by restricted real estate, particularly in the case of shelters in the basement of buildings surrounding a court yard.

3.05 REFERENCES

3.01 "Building Exits Code," National Fire Codes, 1962-63 edition,
Vol. III, Building Construction and Equipment, National Fire
Protection Association, International, 60 Batterymarch Street,
Boston 10, Massachusetts.

3.02 "Design of Entrance Systems," Armour Research Foundation,
December 1959, U. S. Naval Civil Engineering Laboratory,
Port Hueneme, California.

TABLE 3.01

DIMENSIONS OF ELEMENTS

ELEMENT	DIMENSIONS	
	WIDTH	HEIGHT
Doorway		
Minimum (one unit)	22"	$\geq$ 6'-6"
Maximum*(two units)	44"	
Corridors**		
Minimum	30"	$\geq$ 7'-0" (less than 44" width)
		$\geq$ 8'-0" (more than 44" width)
Stairs***		
Single	30"	$\leq$ 8'-6" between landings
Double	48"	

  *Single leaf
 **Also ramps with less than 10% slope
***Risers $\leq$ 7-3/4"; run $\geq$ 9-1/2

Balanced Systems:

1. At least 1-unit doorway (22") with 1-1/2 unit stairway (34").
2. Better is 1-1/2 unit doorway (34") with 2-unit stairway (44").

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Straight Line Entrance
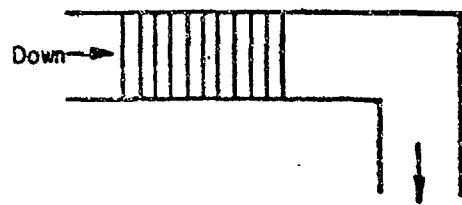
Angled Entrance
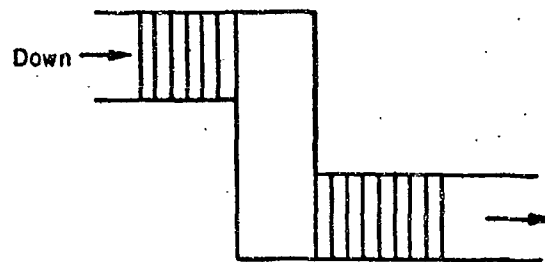
"Z" Entrance
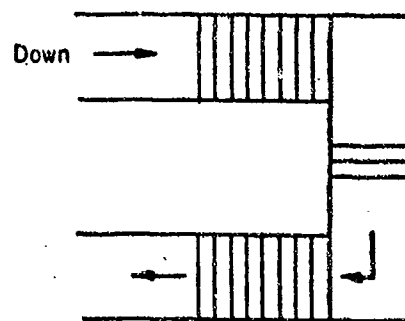
"U" Entrance

FIG. 3.01   BASIC ENTRANCE TYPES
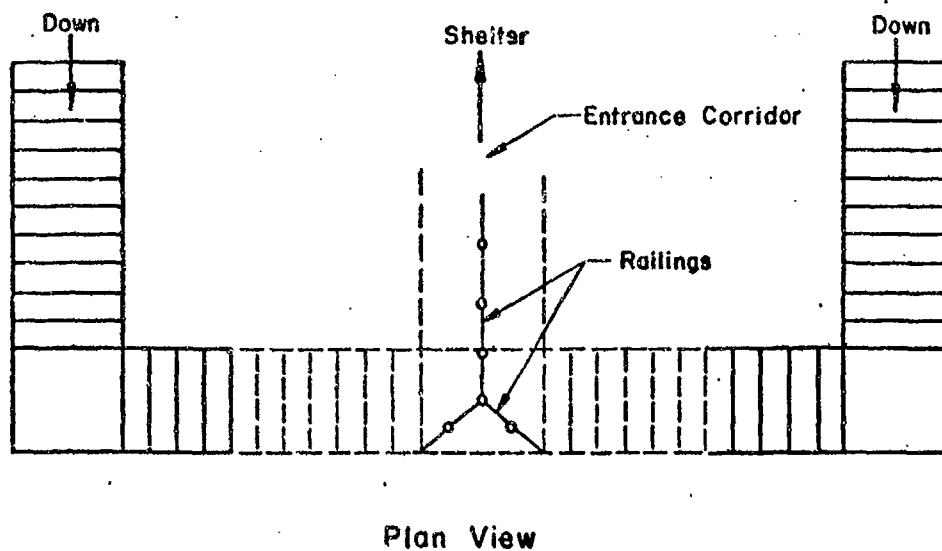
Plan View

FIG. 3.02 MULTIPLE DEPTH ELEMENTS SERVING SINGLE SHELTER
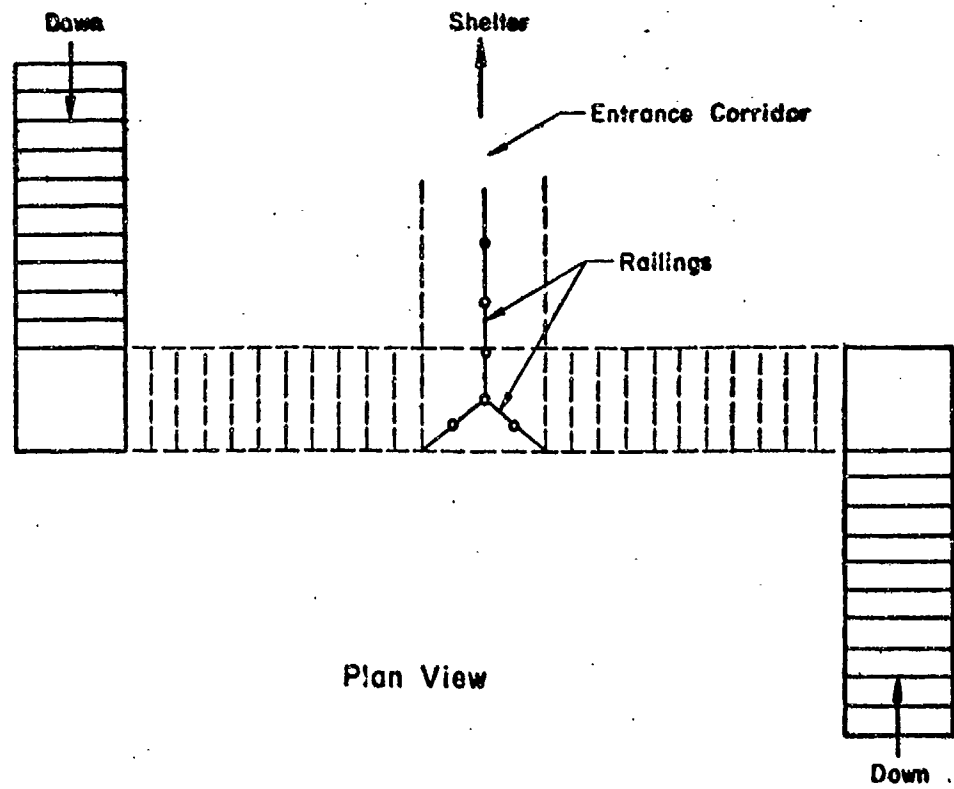
Plan View

FIG. 3.03 MULTIPLE DEPTH ELEMENT SERVING SINGLE SHELTER
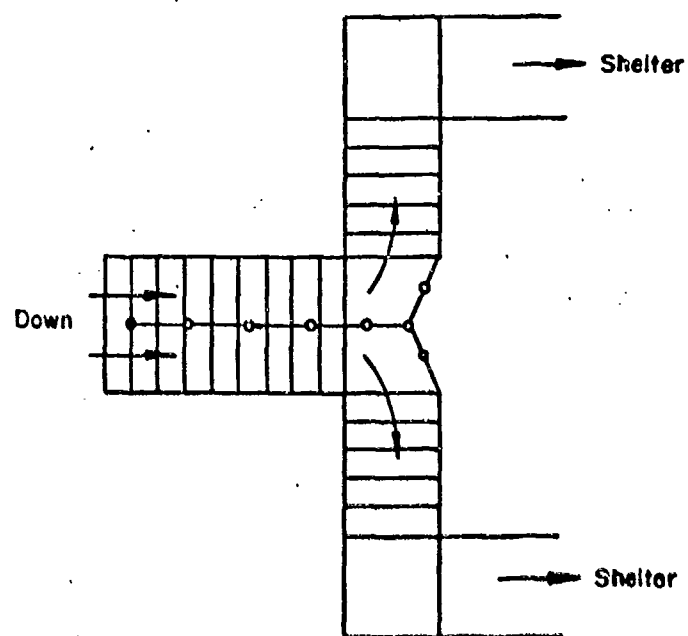
Plan View

FIG. 3.04 SINGLE DEPTH ELEMENT SERVING MULTIPLE SHELTERS

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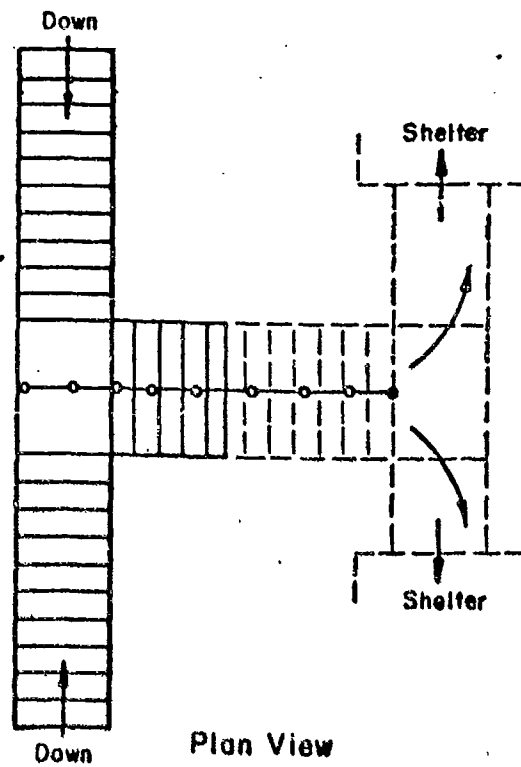
FIG. 3.05 MULTIPLE DEPTH ELEMENTS SERVING MULTIPLE SHELTERS

CHAPTER 4.   VENTILATION SYSTEMS

4.01   INTRODUCTION

The prime objective of this chapter is to discuss and state the specific assumptions made in relation to the ventilating system. Although all elements of the ventilating system are included, they are discussed only as they influence the air intake or exhaust structures, including blast valves.

4.02   ELEMENTS OF VENTILATION SYSTEM

Any shelter which is to house a large number of people in a minimum space must have a forced air ventilation system. As a minimum such a system would consist of air intake and exhaust passages and a means of forcing the air to circulate. As both the pressure and size of weapon for which a shelter is to provide protection increase, the ventilating system becomes more complex. For the pressure levels and weapon yields considered in this report the minimum additional equipment required would be a blast valve or mechanism for restricting the flow through each ventilation passage during the period that the shelter is subjected to high pressure. If it is economically feasible to provide a higher level of protection, both particulate and gas filters should be added to the system. Although no consideration will be given in this report to the possible requirement for filtering chemical and biological warfare agents from the incoming air, it is believed that provision should be made in the design of the ventilation system for future installation of such a filter unit.

For community shelters, in which large numbers of people are to be accommodated it is impractical to consider manually operated air handling units such as those recommended for family fallout shelters. The limited capacity of this type unit would require that a large number of them be installed, thus increasing the problem of protection against blast and the maintenance requirement. In addition, the operation of such units would increase the buildup of CO_2, the rate of oxygen depletion, and the buildup of heat and humidity within the structure, thus increasing the ventilation requirement. The labor expended in the manual operation of these units

would require that more water and food be furnished than that required
for survival under the assumed conditions or planned for community
shelter stocks.

Air handling units which are driven by electric motors would
be much more satisfactory than manually operated units. A source of
electrical power is required for lighting the shelter and this source
should be of sufficient capacity to provide power for the motors. The
electrical power could be provided by the normal electrical distribution
system during periods of preparedness before an attack. However, it must
be assumed that the normal source of power would be disabled by any attack
and an emergency source of power must be provided. The most practical way
to provide emergency power would be with gasoline or diesel motor-generator
sets. All combustion engines require large quantities of air for both
cooling and the combustion process. The location of such an emergency
power system within the shelter would increase the total volume of air
which the shelter ventilating system must handle by an order of magnitude.
The location of the emergency power unit therefore greatly effects the size
of the ventilating system required for the shelter.

When power operated air handling units and filter systems are
utilized for a shelter the limitation on the pressure buildup within the
ventilating system becomes much more stringent. Both of these types of
equipment cannot be subjected to large shocks or sustained high pressures
which would disable them. To prevent such high pressures from being applied
to this equipment it may be necessary to add a plenum or expansion chamber
between the air duct and this equipment. Such a chamber would provide a
volume into which high pressure air entering the system before the blast
valves have closed completely can expand to a lower pressure which would not
damage the filters or air handling unit. The size of the plenum chamber
required is dependent on the pressures that the combination of filters and
air handling units chosen can withstand, and the peak overpressure and dura-
tion of the shock which "leaks by" the blast valve before closure. Very
simple baffle systems between the blast valve and the filters can be utilized
to create a turbulent flow which will prevent large peak pressures from
impinging on the filters. The buildup of the average pressure within the
chamber is dependent on the quantity of air which comes through the intake

duct while the valve is closing and the volume of the chamber. Estimating the pressure upstream of the valve and the closure characteristics of the valve, the maximum pressure buildup within the plenum chamber can be computed to sufficient accuracy assuming a reversible adiabatic process. These same methods can also be used to estimate the buildup in the pressure within a shelter due to leakage of air through the various other openings into a shelter such as the cracks around the edges of blast doors.

4.03 INTAKE AND EXHAUST STRUCTURES

For the purposes of this discussion each air intake or exhaust structure is assumed to consist of the duct and the structures supporting both ends. The size of duct required to provide for the minimum acceptable air flow for the personnel occupying a shelter is reasonably small. To provide three cubic feet per minute per person a duct only 6 inches in diameter would be required per 100 occupants. If 16 cubic feet per minute per person were required the duct size would only increase to 14 inches. The choice of the minimum acceptable air flow for any given shelter is dependent upon the choice of the maximum acceptable effective temperature and the climatic variations in the geographical location.

The complexity of each intake or exhaust is dependent upon whether it is built as an independent unit or incorporated as part of the entrance system. For those intake or exhaust passages which lead directly from the shelter to one of the entrance passages the only requirements are that the proper size passage be provided through the wall of the shelter and flanges be provided at each end for the installation of protective baffles or blast valves. If the duct leads from the interior of the shelter to the ground surface sufficient bends must be provided in the duct to give protection against direct penetration by the initial radiation and the exterior end of the duct must be protected against the normal elements of the weather, as well as the high overpressure and debris that would exist at the ground surface from an explosion. The size of the protective structure at the end of the ducts is not large and it need not be very complex. Such a structure should rise above the ground surface only a sufficient distance to preclude the entrance of debris and rain or snow. Several previous

shelter designs have incorporated the blast valve into this supporting structure. The location of the blast valve at this point complicates any provision for operation of the valve from within the shelter and raises the possibility of unnecessarily exposing maintenance personnel to high radiation if maintenance is required after an attack. Therefore, it is recommended that the valve be located on the interior end of the duct so that it will be protected from the normal weathering and be more accessible for maintenance and manual operation. The location of the blast valve at the interior end of course precludes any complication in the supporting structure required at the exterior end. Such a structure could consist of a heavy pipe extending above the ground surface with a weather protective head or a pipe extending into a cavity in the center of a more massive reinforced concrete and steel structure which would provide protection from the normal elements of the weather and also give better protection from the high ground surface overpressures, dynamic pressures, and flying missiles. The normally available rigid pipe or flexible pipe will be adequate for the ducts for the overpressure levels being considered.

The location of individual intakes and exhausts will be dependent upon the overall configuration of the shelter entrance system. In any event, advantage should be taken of the entranceway configuration as a means of providing both radiation and physical protection for some of the ducts. If sufficient entrances are available all inlet and exhaust passages should terminate in an entranceway. Where sufficient entrances are not available the intakes should be placed in the entrances in preference to the exhausts. This recommendation is based on the consideration that subsequent to an attack there is less likelihood t it an entrance would be completely blocked by debris than would a separate ground surface protective structure. The velocity of the air through the entranceway also would be much lower than in the duct and there would be less likelihood of drawing radioactive particles into the shelter.

4.04 EMERGENCY POWER PLANT LOCATION

The operation of any emergency power plant which uses gasoline or diesel oil as fuel requires a large supply of air. This air is needed both for the combustion process and the removal of the heat ejected by the

motor. The volume of air required is large compared to that needed for the sheltered personnel by an order of magnitude. In a shelter for 100 people the power source would require at least 3,000 or 4,000 cubic feet of air per minute. If the generator set is located within the shelter proper this air supply would have to be provided through a duct system almost as complex as that required for the air supplied for personnel. Although locating the power source inside the shelter proper would make it accessible for maintenance and thus somewhat more reliable, the increased costs and size of the additional ventilation facilities required may be prohibitive as compared to other solutions to the problem.

If the motor generator set is located exterior to the shelter proper, the total power requirement may be decreased considerably and only the air required for the comfort of personnel needs to be handled by the shelter air handling units. When locating the generator set exterior to the shelter proper it could be housed in an independent protective structure or it could be provided with nominal protection from the direct forces of the explosion. If the power source were installed in its own protective shelter two possible methods of protection could be used. Large inlet and exhaust passages could be provided which would each have a blast valve to limit the pressure buildup in the protective shelter or rather small inlet and exhaust passages could be used without the blast valve and the pressure allowed to build up around the generator. The latter type of installation would protect the generator from the application of rapidly rising pressures and shock waves. Each of these systems would require that power operated air handling units be utilized to insure sufficient flow of air through the structure so that the power unit would not over heat. With the air handling units being required for this location of the power source the total power requirement would not be reduced.

If the power source were located in a relatively unprotected location such as in the end of an entrance passage or in an open pit adjacent to the entrance or shelter, normal air circulation could be relied upon to provide the necessary cooling and the air for combustion. This would reduce the power requirement per shelter considerably and would not decrease the probability of survival of the emergency power system very much if suitable motor-generator sets were utilized. As part of past

nuclear test programs several generators were subjected to the effects of high pressure. Although these generators did not always continue to operate during and after the actual explosion, the damage which occurred was usually minor in nature. By making minor changes in the construction of standard motor-generator sets it is possible to build sets which can withstand the pressures being considered in this report.

Locating the generator in a space provided at the end of one of the entranceways would be more advantageous than locating it in a relatively open pit. For such a location the pressures and drag forces would be somewhat less than would occur in an open pit and the generator would be much more accessible for maintenance. However, location of the generator in an entranceway does preclude the use of this particular entranceway as a possible location for any of the intake ducts for the shelter. The exhaust ducts could vent into the same space which houses the generator provided that a positive pressure was always maintained within the shelter. If sufficient additional entranceways were not available to allow for the installation of all intakes in the other entranceways, separate structures could be used for the intakes.

4.05 BLAST VALVES

The major operational requirement of any blast valve is that it closes before sufficient air volume is forced through the duct by the high pressures from an explosion to cause damage to either the mechanical equipment or the personnel in the shelter. Such valves can be remotely operated by blast, light, or radiation sensors and auxiliary power sources or by the blast itself. Several valves of each of these types have been tested in the nuclear test program. Although many of them proved satisfactory for the specific purpose for which they were designed, no single valve has been completely satisfactory from the standpoints of low cost of manufacture, low maintenance costs, and reliability. Considerable additional effort is required to develop more suitable and economical valves. Shelters can be planned and built which utilize the presently available valves and better, more economical valves installed at a later date, when they become available.

In general the closing times required by the remotely operated valves are entirely too long for use in the shelters being considered here.

Several of the blast actuated valves operate at a sufficiently rapid rate
to preclude the buildup of high pressures in the shelter. To keep the
initial high pressure shocks which might enter the shelter from damaging
complex filter systems, plenum or expansion chambers would be required.
If only simple particle filtration systems are to be used, such plenum
chambers may be eliminated by providing a relief section in the duct ahead
of the filters and air handling equipment so that any shocks would be
vented directly into the shelter. This section could then be replaced
and, if the filter had been damaged, a new one installed.

Several new blast valves should be designed specifically to fulfill the
requirements of shelters discussed in this report. In addition, possibili-
ties other than blast valves should be explored. Certain systems such as
filters which are not damaged by high pressures and vary in their capacity
to conduct air in proportion to the pressure across them should be explored.
Several studies of this nature are currently underway and preliminary
results seem promising. It appears that materials can be used in such
filters so that as the blast engulfs the structure the flow through the
filter during the period of the high overpressure will be low enough to
limit the pressure within the shelter to acceptable values.

References 4.01 and 4.02 summarize information on the physical
characteristics, operational performance, test results, etc., of many of the
presently available blast valves. This information is not reproduced herein.

4.06 CONCLUSIONS

The following conclusions are offered:

1) The air intake or exhaust elements of the ventilating system
should be incorporated in the entranceway structure where possible.

2) Emergency power plants should be located in an entranceway;
however, entranceways which house emergency power plants should not be
utilized to house intake elements, but can be used to house shelter exhaust
elements.

3) Blast valves should be automatic in their actuation.

4.07 REFERENCES

4.01 Hassman, M. & Cohen, E., "Review of Blast Closure System," Proceedings of 29th Symposium on Shock, Vibration and Associated Environments, Part III, July 1961, Bulletin No. 29, Office of Secretary of Defense, Research & Engineering, Washington 25, D.C.

4.02 Kessler, J. and Levoy, L., "A Study of Blast Closure Devices," AFSWC, TDR-62-10, February 1962, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico.

CHAPTER 5. EFFECTS INPUT DATA

5.01 INTRODUCTION

This chapter contains the weapons effects input data for which the entranceway and ventilation systems must be designed. Included are the blast effects, prompt nuclear radiation, residual nuclear radiation, and thermal radiation. The discussion of all of these effects is related to a specific overpressure (50 psi) from a specific yield weapon (1 MT). There may be other overpressures and weapon yields of interest. The data presented below on prompt nuclear radiation should be used with caution for conditions which differ greatly from those assumed. However, the characteristics of the blast wave and intensity of associated thermal and ionizing radiation may be obtained from Ref. 5.01 for any specified overpressure and weapon yield.

5.02 BLAST EFFECTS

1) _Free Field Data._ Having decided upon the overpressure level and the weapon yield of interest (e.g., 50 psi and 1 MT are used for illustrative purposes in this report) the free-field overpressure vs. time relationship can be established. Fig. 5.01 was prepared from data contained in Ref. 5.01.

2) _Attenuation in Tunnels._ Since 1958, considerable research effort has been expended on the problem of the entry of shock waves into tunnels and the subsequent behavior of these waves in various tunnel configurations (Ref. 5.02). Unfortunately, very little of this effort can be applied to the problem at hand because the passages under consideration are too short to permit the shock wave to reform inside. As indicated in Fig. 3.1, Ref. 5.02, the shock wave does not reform until it has reached a distance down the entranceway equal to approximately 5 to 10 tunnel diameters. However, some of the basic relationships established can be used to obtain a qualitative picture of what might be anticipated in the entranceway and particularly what loads may be anticipated on blast closure devices, such as doors and blast valves.

From Fig. 3.6 of Ref. 5.02, the maximum pressure which may be anticipated in the entranceway is a function of the peak overpressure outside and the angle of incidence between the shock front and the opening. At the 50 psi overpressure level the free field shock front may be assumed to be perpendicular to the idealized plane in which the shelter is located.

(a) <u>Tortuous Entrance Tunnels</u>. For purposes of discussion assume an entrance configuration as shown in Fig. 5.02. The worst case orientation occurs when the shock wave meets the entrance as indicated in Fig. 5.03. As the shock wave turns down into the entranceway the peak overpressure in the front is decreased. Upon reflection from the wall at the base of the first flight of stairs, the peak reflected pressure will be somewhat less than that which can be predicted for normal incidence of the free-field shock front.

As shown in Fig. 5.04, prior to reflection from the wall at the base of the stairs, the shock front will turn the corner into the second leg of the entrance structure and a vortex will be formed at that corner. The pressure in the front indicated as P_1 will be less than the peak pressure in the stairwell before the front turned the corner. The latter pressure, as stated, would be less than the side-on pressure at the surface.

Subsequently, the shock wave will reflect from the wall at the base of the stairs. The pressure P_3 will be less than the reflected pressure of the free-field front at normal incidence. Further, the pressure P_2 will be less than the pressure P_3. As the reflected front progresses further down the second leg it will encounter the vortex formed at the corner and subsequently the reflection of the front which preceded it. The shock picture then becomes more confused as it turns down the third leg, so confused, in fact, that a quantitative analysis is not possible.

For such configurations it is necessary to rely on available data for a decision as to design criteria for blast doors and valves further down the entrance corridor.

If the shock front were coming from the direction opposite to that shown in Fig. 5.03 there would be no reflection from the wall at the base of the stairs and there is some evidence to indicate that the maximum pressure in the entranceway would be approximately equal to the peak side-on overpressure outside (Ref. 5.03).

For other angles of entry the loading on the various portions of the entrance structure will vary between these two extremes, except that the worst case for the walls adjacent to the first flight of stairs will occur when the shock front crosses the stairs at right angles. Thus, each portion of the structure must be designed for its own worst case condition, or the probability of obtaining the worst case must be accepted as a calculated risk. In the discussion which follows, the loadings derived for the various elements of the entrance structure will be based on what is believed to be the worst case orientation.

The pressure on any element of the entrance structure is affected also by the fact that the side-on overpressure at the surface is decaying with time. After the initial entry and subsequent reflections the pressure inside the entrance structure will reach equilibrium, for all practical purposes, with the pressure existing at the entrance. If the shock wave is of relatively long duration it is reasonable and conservative to assume that the pressure does not decay with time and the equilibrium overpressure is the peak side-on overpressure.

The clearing time for a tunnel, or time at which equilibrium is reached, may be approximated by computing the time required for the shock to traverse the entire length of the tunnel and return. This will be considered in more detail later.

(b) Short Straight Entrance Tunnels. The entry and subsequent reflection of shock waves in short straight tunnel sections has been investigated and is discussed in Ref. 5.02. Such configurations should be avoided because the reflected pressure on the blast closure devices (doors and valves) can be greater than the reflected pressure of the shock front in the free-field at normal incidence. Further, bends in the entrance tunnel in general are desirable for radiation attenuation.

(c) <u>Long Entrance Tunnel Configurations</u>. If for some
reason the lengths of the individual legs of the entrance tunnel exceed
10 times the average cross-sectional dimensions, a more detailed study
of the behavior of the shock wave in the tunnel is possible. For these
cases the reader is referred to Ref. 5.02.

3) <u>Air-Induced Ground Effects and Loads on Structures</u>. For
a 1 MT weapon at the 50 psi overpressure level and for the shallow
depths of interest, it may be assumed that the vertical component of the
overpressure does not attenuate with depth in the soil.

Generally the horizontal stress, p_h, in the soil is taken as
some constant, K, times the vertical stress, p_v, or $p_h = Kp_v$. The magnitude
of K depends on the properties of the soil, the degree of saturation,
the stress level, and the conditions of lateral strain imposed on the
soil element.

A detailed discussion of the influence of these factors on the
value of K is given in Ref. 5.04. For the case of zero lateral strain,
K is denoted as K_o and recommended values for a number of soil types are
given in Table 5.01.

The loads produced on the structure by the above air-induced
ground effects are complicated by the interaction between the soil and
the structure. Among other variables it is known that the stiffness
of the structure, the manner in which it is supported, and the direction
of motion of the structure (i.e., whether passive or active earth
pressures are involved) all have significant bearing on the stress at
the soil-structure interface.

Methods for estimating the blast-induced loads of fully buried
rectangular structures are given in Ref. 5.04. These methods are
adapted to the configurations and depths of interest in the following
paragraphs.

Horizontal elements of the entrance structure will be subjected
to the direct effects of the air blast overpressure if they are flush
with the ground surface. The same pressure will be transmitted to
buried horizontal elements if the depth of burial is shallow and the
attenuation of the vertical component of the overpressure and the arching

of the soil above the element are small.. This is the case for the depths under consideration in this study.

The blast-induced loads on vertical elements of a buried rectangular structure are somewhat more uncertain than those for the roof and base slabs. Because of the uncertainties in the relation between the horizontal and vertical free-field pressures and in the effects of arching, it is recommended that the walls elements be designed for the vertical pressure multiplied by the values of K_o given in Table 5.01. This procedure is considered to be consistent with the present state of knowledge and, though possibly conservative, is probably not unduly so.

The above recommendations apply when the loads transmitted through the soil are greater than the pressure inside the structure. For the condition which exists when the reflected pressure inside the structure is greater than that transmitted through the soil, the walls of the structure will deflect outwards and a passive resistance will be mobilized in the soil. Thus, the pressure differential will be reduced.

A rational analysis under this loading condition requires a knowledge of the "subgrade modulus" of the enveloping soil, k, in pounds per square inch per inch of deflection. This modulus is a function of the size of the loaded area, the pressure level, and the deflection as well as of the soil type. Few data are available to assist in making a reasonable estimate of a value for design purposes. Table 5.02 gives values which are indicative of the order of magnitude which may be expected. They have been interpolated from very limited data for the structure size and soil types of interest.

It is important for the backfill to be thoroughly compacted in order to achieve a maximum value of subgrade modulus. If there are voids behind the wall or if the backfill is dumped loosely in place values of subgrade modulus less than 10 psi per inch of deflection may be expected. The backfill should be compacted to 90% or more of Proctor density to assure satisfactory and uniform results.

5.03 LOADING ON ENTRANCE STRUCTURE ELEMENTS

1) _General._ In the two previous sections the loading on various elements of underground entrance structures has been discussed. The

purpose of this section is to summarize that information in terms of
loads for which the various elements should be designed.

Whether any given element will be subjected to a load through
the soil before the shock wave in the air arrives is dependent upon the
velocity of the shock wave in the air, the velocity of the stress wave
in the soil and the distances they each must travel. To a certain
extent the time sequence of loading is dependent upon the orientation
of the structure with respect to the direction of shock propagation in
air.

The velocity of the shock wave in the air may be computed from
the following expression (Ref. 5.01):

$$ U = C_o \left[1 + \frac{6p}{7P_o} \right]^{\frac{1}{2}} $$

where U = air shock velocity, fps

C_o = velocity of sound in air, fps (1117 fps at standard conditions)

p = peak overpressure in air shock, psi

P_o = atmospheric pressure, psi (14.7 psi at standard conditions)

Values for the seismic velocities of various soils are listed
in Table 5.03. Note that for most soils the velocity of stress wave
propagation is greater than the velocity of the shock wave in the air at
50 psi (U = 2200 fps). Structures in such soils will be subjected to
loads transmitted through the soil before the air shock wave arrives.

The problem of determining the pressure as a function of time
on a structure below ground is quite complex and is the subject of
considerable study at this time. What follows is not offered as a solution
to the problem, but only as a basis for a decision as to the magnitudes
and directions of the applied loads.

2) <u>Walls Adjacent to Open Stairwell</u>. The worst case orientation
for the walls adjacent to the open stairwell is indicated in Fig. 5.05.
As the shock front approaches the shelter entrance, the wall closest to
the point of detonation may be loaded by stress propagating through the

soil before the arrival of the shock wave in the air if the velocity of
stress propagation (c) is greater than the shock velocity (U). This
load will gradually build up from the normal load which exists to a
value $p_h = K_o p_{so}$ just before the shock front spills over the edge of the
wall. The length of time between the beginning of a build-up of active
earth pressure and the time that the shock wave fills the entrance is
on the order of 10 milliseconds. Therefore, it is reasonable, since the
retaining wall is a relatively stiff structure, to design the walls for
an active earth pressure of $p_h = K_o p_{so}$ acting inward.

If there is a blast door at the outside entrance, so that the
shock wave could not enter, this pressure, $p_h = K_o p_{30}$, would be applied
to both walls of the stairwell.

If there is no blast door at the outside entrance, the shock
wave will turn the corner as indicated in Fig. 5.05, and will reflect
from the opposite wall beginning at the top. The peak reflected over-
pressure at the top may be calculated from the following expression
(Ref. 5.01):

$$p_r = 2 \, p_{so} \left[\frac{7p_o + 4p_{so}}{7p_o + p_{so}} \right]$$

where p_r = peak reflected overpressure and p_{so}, p_o are as defined above.

For design purposes, a reasonable approximation to this complicated
loading picture may be obtained by assuming that the entire wall facing
the shock is subjected to the peak reflected overpressure instantaneously.
The clearing time, or, the time at which the pressure on the wall facing
the shock wave drops to the side-on overpressure, may be approximated by

$$t_c = \frac{3h}{U}$$

where t_c = clearing time, sec.

h = height of wall, ft.

U = shock velocity at side-on overpressure, fps

For the top of the wall at least, the reflected overpressure
will be applied instantaneously before the soil mass behind the wall
is restrained by the side-on overpressure acting on the surface of the
soil. Thus, the motion of the top of the wall will be resisted initially
only by the passive earth pressure of the soil (with no surcharge).

However, as the shock front progresses down the wall and along
the surface of the soil beyond the slab, resistance to lateral motion
of the wall builds up very rapidly. Further, complete failure of the
wall cannot occur without developing the passive earth resistance of the
soil behind the wall,

This is a complex problem in soil-structure interaction under
dynamic load and a detailed study of it is beyond the scope of this report.
An approximate approach which is believed to be reasonably conservative
is to design the wall for the forces indicated in Fig. 5.06 acting
statically. That is, it is assumed that the wall facing the shock wave
is subjected to a static pressure equal to the reflected overpressure
(p_r); the pressures resisting the motion of the wall are

a. $K_p p_{so}$; (passive resistance due to surcharge)

b. $2c\sqrt{K_p}$; (passive resistance due to cohesive strength of the soil)

c. $\gamma z K_p$; (passive resistance due to the unit weight of the soil)

where $K_p = \dfrac{1 + \sin \phi}{1 - \sin \phi}$; coefficient of passive earth pressure

ϕ = angle of internal friction of the soil

p_{so} = side-on overpressure at surface, psi

c = cohesive strength of the soil, psi

γ = unit weight of the soil, lbs/in^3

z = depth below surface, in.

For a saturated clay $\phi = 0$ and c is one-half of the unconfined
compressive strength of the soil.

3) Slab Over Landing. The worst case orientation for the slab
over the landing at the base of the stairs is shown in Fig. 5.07. The
loading on top and bottom of the slab over the landing may be assumed
to be equal until the shock front reflects from the wall at the base of

Sec. 5.03

the stair. At that time the load on the bottom is the reflected over-pressure and the load on the top is the side-on overpressure.

After some period of time an equilibrium condition may be assumed to exist; in fact, there should be some small excess overpressure acting up at the bottom during the entire positive pressure phase. The net loading may be approximated by the loading indicated in Fig. 5.07.

The rise time of the pressure pulse may be expressed approximately as

$$t_r = \frac{b}{U_r}$$

where t_r = rise time, sec

b = width of slab, ft.

U_r = velocity of reflected shock front, fps (1200 fps for 50 psi)

The clearing time may be expressed as

$$t_c = \frac{3b}{U}$$

where t_c = clearing time, sec

U = shock velocity, fps (2200 fps at 50 psi)

The use of the loading function in Fig. 5.07 requires a knowledge of the periods of vibration of the slab over the landing. An approximate and more conservative approach for design purposes would be to design the slab over the landing for the side-on overpressure acting downward or, if there is no blast closure at the entrance, for a pressure equal to $(p_r - p_{so})$ acting upward. In either case, compression steel equal to one-half of the tension steel should be provided for reversal of loading, rebound, and to insure ductility.

4) <u>Corridor Section Below Ground</u>. Because there will be a considerable time lag between the arrivals of the stress wave through the soil and of the air shock wave through the tunnel, in the general case vertical walls below ground will be subjected to a lateral pressure $p_h = K_o p_{so}$ acting inward regardless of whether there is a blast door at the entrance or not.

If there is no blast door and the entrance is tortuous as described in Sec. 5.02, the pressure inside will gradually build up to a pressure greater than $K_o p_{so}$. As discussed in Sec. 5.02, the outward lateral motion of the walls will tend to develop the passive resistance in the soil, if sufficient lateral wall displacement occurs. Even if the wall is too stiff to develop the full passive resistance of the soil prior to failure of the wall slab, a rational analysis requires that some consideration be given to the restraint developed by whatever displacement occurs. This can be accomplished by employing the "subgrade modulus" for the soil as listed in Table 5.02.

That is, for the case where there is no blast door at the outside entrance, the pressure on the inside of the walls (acting outward) will be $2 p_{so}$. This load is resisted by the slab, the lateral earth pressure $K_o p_{so}$, and, by a pressure $k x_u$ where k is the "subgrade modulus" and x_u is the ultimate deflection of the wall at mid height. Here ultimate deflection is defined to be the deflection corresponding to the ultimate moment capacity of the section and for design purposes may be assumed to be ten times the yield deflection of the member.

In the discussion above it is tacitly assumed that the resistance developed in the soil by the deformation of the wall is everywhere equal to that computed using the ultimate deflection of the wall at mid-height. That is, no consideration is given to the actual deflected shape of the wall. While this simplification may seem crude, current knowledge of "subgrade modulus" does not warrant further refinement.

The roof slab must be able to resist the side-on overpressure acting on the surface, the dead load of the slab and the soil overburden, all acting inward, whether or not there is a blast door at the outside entrance. If the shock wave can enter the corridor the roof slab will also be subjected to a pressure equal to $2 p_{so}$ acting outward.

Similarly, the floor slab will be subjected to the side-on pressure plus the entire dead load of the section acting inward. Unless better information regarding the distribution of pressure in the soil in question is available it is suggested that a uniform distribution of pressure be assumed. Then, too, if the shock wave can enter the corridor

the floor slab will be subjected to a pressure of $2 p_{so}$ acting outward at some later time.

The loading conditions discussed above are summarized in Fig. 5.08.

5) Interior Doors and Valves. As stated in Sec. 5.02 the dimensions and configurations of the entranceways are such that it is not possible to compute the loading as a function of time on blast closure devices at the interior end of the entrance corridor. Based on experimental data available, the average peak overpressure on such closures can be as low as the side-on overpressure outside and as high as about twice the side-on overpressure outside (Ref. 5.05). Even in the latter case the loading is not a true shock loading, i.e., the overpressure rises erratically to a maximum value of about twice the peak side-on overpressure outside.

Therefore, it is conservative to assume that blast closure devices located in corridors or ducts are subjected to an infinite step-pulse with a maximum overpressure of 100 psi.

6) Exterior Flush Door. The loading on an exterior flush door at the outside of the entrance structure is dependent on the peak incident overpressure and the weapon yield (50 psi and 1 MT for this report), the orientation of the door with respect to the blast wave, and the dimensions of the structural face housing the door.

The orientation of the door with respect to the blast wave determines the peak reflected pressure to which the door is subjected. This reflected pressure may vary from the peak incident overpressure (i.e., 50 psi) for a horizontal door, or vertical door facing away from the blast, to the full reflected pressure (i.e., 200 psi) for a vertical door facing the blast. Reflection factors, i.e., the ratio of the reflected pressure to the incident pressure, for various incident pressures are presented in Ref. 5.01 (Fig. 3.71b). An idealized relationship between the reflected pressure and the angle of incidence for 50 psi is plotted in Fig. 5.09.

The dimensions of the structural face housing the door determine
the duration of the reflected pressure spike; the smaller these dimensions,
the shorter the duration of the reflected pressure. However, it is
conservative to assume an infinite duration step pulse of the reflected
pressure. If desired, a more precise load-time history can be evaluated
in the manner described in Ref. 5.01 (Chapter 4) and the required
structural resistance determined using the methods described in Refs.
5.06 and 5.07.

5.04 PROMPT RADIATION EFFECTS

1) _Introduction_. For analysis of shelter shielding effective-
ness it is necessary to know the amount of radiation of each type, of
various energies, and its incidence on the shelter from each direction.
This must be known, if not precisely, at least roughly. Various factors
enter into such a determination, e.g., the distance from the weapon
explosion, the angle of line of sight above the horizon, the orientation
of the shelter relative to the direction of the line of sight, the type
of weapon, and the size of weapon.

Most of the available information relates to the total initial
flux or dose measured at various distances from a nuclear explosion of
a certain size. For the purposes of this report, it is assumed that a
reasonable estimate of this total can be made and the data given in
"The Effects of Nuclear Weapons" (Ref. 5.01) is valid. On the other hand,
the proportion coming from the various directions, the division among
the various energy groups, and the bi-parametric distribution of
proportion both in energy and direction are very poorly known. However,
for design purposes it is necessary to make some estimate of the situation.
The estimate which follows is based on presently available unclassified
information for the specific condition of particular interest, i.e., at
a distance on the order of one mile from the explosion a nuclear weapon
in the megaton range. This is the approximate range for the 50 psi level
for a 1 MT weapon.

2) Energy and Directional Distribution Parameters

(a) General. It is impossible to find data on energy and directional distributions for precisely the circumstances considered in the present problem. However, it can be demonstrated that moderate variations from the basic input data are of minor importance. This is fortunate since it permits the use of certain experimental and analytical data presented for slightly different situations, and it makes any criteria derived useful over a range of situations instead of being applicable only to the precise situation assumed herein. A discussion of the importance of the various parameters in the problem follows.

(b) Energy Spectrum Variation with Distance. Ref. 5.01 (para. 8.84) states with regard to the gamma energy spectrum: "... the energy spectrum observed at a particular distance from the explosion will be different from that at almost any other distance because the various components are degraded in energy and absorbed differently in their passage through air or other attenuating medium." For neutrons, it states (para. 8.96): "... although the total number of neutrons received ... decreases with increasing distance, the proportions in the various energy ranges remain essentially the same throughout."

It is believed that these two statements tend to create impressions which are a bit extreme in each direction. For practical shielding purposes, the variation in the spectrum for gamma rays is probably not great for distance variations of many hundred of feet. Ref. 5.08 (Section 5(γ)) makes a specific point that the distribution of scattered photons within a very few mean-free-paths (say, about a thousand feet in air) reaches a "quasi-equilibrium" condition which varies rather slowly. Ref. 5.09 shows a comparison between the energy distribution of gamma rays at 4500 ft. and 9000 ft., in which the gamma rays from air (nitrogen) capture show no major changes, although the rays from fission products show a certain degree of hardening with distance change of this amount. Since the nitrogen capture effect is shown to provide most of the dose at both these ranges, the overall effect would not lead to any major, rapid changes of spectrum at these distances. .

On the other hand, the statement of Ref. 5.01 with respect
to neutrons is made on the basis that the plotted lines of response
versus distance for various threshold detectors are presumed to be
parallel. Inspection of Fig. 8.95, Ref. 5.01, will indicate that they
are not parallel exactly, and that for large changes in distance a
hardening of the spectrum takes place. Therefore, it is believed proper
to assume that for both types of radiation an energy spectrum obtained
at any point beyond 1000 ft. from the explosion is probably valid for
other ranges within many hundreds of feet of that point, but becomes less
valid at more widely different ranges, although neutron spectral
variations are probably less extreme than gamma ray variations.

(c) Energy Spectrum Variation with Bomb Type and Size.
There appears to be very little in the unclassified literature on this
matter. As long as the weapon is largely a fission yield type, there
should be little essential difference with size, aside from minor
perturbations caused by variations in the detailed design of the weapon
and its casing. A fusion type weapon, on the other hand, can emit high
energy neutrons, around 14 MeV; and the only gamma resulting is that
coming from secondary reactions of the neutrons with the surrounding
medium. Under these circumstances, rather appreciable variation in gamma
and neutron spectrum might be expected, even though a rather similar
state of "quasi-equilibrium" may come into existence after some distance.
However, high yield weapons are part fission and part fusion and the
mixture of the two would provide a spectrum approaching more or less
the fission weapon spectrum. Likewise, an appropriate design for a high
yield weapon is to have the fusion reactants surrounded by a "blanket"
of uranium which will absorb the high energy neutrons from fusion and
thereby fission by interaction with these fast neutrons (see para. 1.67,
Ref. 5.01). Under the circumstances, it appears that the use of the
energy spectrum associated with purely fission weapons is reasonable,
with the qualification that a separate analysis should be made for a
weapon which is largely of the fusion type, should information on its
energy spectrum at reasonable distances ever become known.

For large weapons of any type there is another effect whose influence on gamma spectral distribution can be discussed only in a rather qualitative manner. This is sometimes called the "hydrodynamic effect." It is related to the fact that the creation and expansion of a high pressure, high density shock front, followed by a below atmospheric pressure phase, varies the amount and distribution of air which serves as an attenuating medium for the fission product component of the initial gamma radiation. This variation is a function of time and becomes most significant when the shock front is in the vicinity of the shelter. During this period, the percentage of the radiation due to early fission product decay is greatly enhanced. The greatest effect, of course, is on the total radiation received; but as far as energy distribution is concerned, the overall spectrum will become softer and will appear more like a spectral distribution at a closer range. It is on the side of conservatism to ignore this spectral softening, although the effect on total radiation dose and flux must be recognized.

(d) <u>Directional Spectrum Variation with Distance and Type of Bomb</u>. Ref. 5.10 is quoted as follows: "In the several events for which angular distribution data were obtained in Operation Plumbbob, the angular distributions of both neutrons and gamma rays were observed to be rather insensitive to the type of weapon and to the distance from the burst points." The distances involved in these experiments were from 4065 to 5475 ft. The bomb sizes were all near nominal magnitude. These distances are in the range of interest for this problem, but the weapons sizes are not as large as desired. However, since weapon size is not considered a sufficiently significant factor for varying energy spectrum it can probably also be ignored in connection with variations in directional spectrum.

(e) <u>Effect of Changes in Slope of Line of Sight to Explosion Point</u>. This factor is important because of the presence of the earth-air interface which affects the radiation field. There is a definite effect on the value of the total dose (page 414 of Ref. 5.11; para. 8.32 of Ref. 5.01; and Ref. 5.12), but for angular distribution

on a proportional basis the effect is surprisingly small. Computations by French and Wells (Ref. 5.11) for a homogeneous, isotropic medium are, ignoring their inclusion of the prompt fission gamma rays (which are largely shielded out in practical cases), in very good agreement with the experimental data of Ritchie and Hurst (Ref. 5.10), which were taken in a case for which the line of sight to the explosion was about 20° from the horizontal. There is likewise very little reason to expect any major variation in the energy distribution, on a proportional basis, with change in slope of line of sight.

3) Summary of Available Information

(a) Directional Distribution. The best information available is that of Hurst and Ritchie (Ref. 5.10). It represents the percent of air-dose received by an instrument having an aperture such that it can detect radiation arriving within 15° of the direction in which the instrument axis is pointing. It is noted that peaking of the neutron distribution is not nearly as marked as of the gamma rays. There is no important difference between the Hurst and Ritchie results and the calculations of Ref. 5.11 and the former will be the basis of design criteria used in this report.

(b) Energy Distribution. Data available on energy distribution of gamma rays are roughly, but not precisely, consistent. Graphs of the gamma ray energy spectrum are shown in Fig. 8.85 of Ref. 5.01, Fig. 3 of Ref. 5.11, and Fig. 4 of Ref. 5.09. All the data in the stated references are roughly consistent and are at distances from 3770 ft. to 6000 ft. from a KT size weapon. The data of French and Wells should be corrected by elimination of the prompt fission gammas. The information from Clarke, Melhorn, and Gold is given as relative dose per unit energy band width, and is therefore more immediately useful. In using it, note must be made that the figure for fission product gamma rays includes only those emitted during the first second after the explosion, and to get the total considered as included with the initial radiation it must be multiplied by about 6.

Information on neutron energy spectrum is given in Ref. 5.01 (pages 406 and 407) and in Ref. 5.11 (Fig. 5). These are in rough agree-

ment, although there are minor variations between theory and experiment.
A precise knowledge of the energy spectrum is not highly important,
especially for energies above 0.5 MeV, since above this energy the varia-
tion of dose with energy is rather small.

(c) Combined Energy and Directional Distributions. The
information on this subject is sketchy. Some experimental information
on neutrons is available in Ref. 5.10. Theoretical information is
provided by Ref. 5.11 on neutrons, which is compared with the experimental
data. For gamma rays, the only information found is the analysis in
Ref. 5.11 which provides separate information on fission product gamma
rays and air-capture gamma rays. Since the latter have much higher
energies present, this should provide some understanding of the difference
in behavior (if any) of the high energy and the low energy component of
the radiation.

For gamma rays from fission products, the angular distribution is
slightly more peaked than for air-capture gamma rays (Fig. 4 of Ref. 5.11).
However, since the air-capture gamma rays originate from a rather diffuse
source (several hundred feet in effective radius around the burst point),
the difference in angular distribution is probably not greatly related
to the difference in energy distribution of the two components at their
source. It may be surmised on fundamental grounds that the radiation
which arrives from directions radically different from the line of sight
to the explosion point will not have any high energy components. On
the other hand, that arriving in directions near the line of sight will
contain all the high energy component of the radiation, and will also
contain some low energy radiation.

The information available from the two references cited above
indicate that a similar picture applies for neutrons. The high energy
neutrons are more likely to come from a direction near the line of sight
than from a more scattered direction, whereas the low energy neutrons
show a greater degree of isotropy. However, for neutrons this relationship
of direction and energy does not seem to be quite as marked as in the case
of gamma rays.

4) Assumed Prompt Radiation Input Data

(a) <u>General</u>. It is assumed that the total gamma ray exposure dose in the open is known, and that the total neutron flux in the open is known. These can be obtained from Ref. 5.01 or classified sources.

It is to be emphasized that the prompt radiation input herein has been selected for the shelter entranceway problem, and is conservative from that point of view.   It is   not necessarily conservative from the standpoint of shelter roof attenuation.

(b) <u>Gamma Rays</u>. The following dose angular distribution for gamma rays is considered reasonable for ranges of approximately one mile:

> 40% of the dose arrives from direction within
> an angle of 15° from the line of sight;
> 40% of the dose arrives from directions between
> angles of 15° and 40° from the line of sight,
> equally distributed above the horizon;
> 20% of the dose arrives directions from directions
> beyond 40° from the line of sight, equally
> distributed above the horizon.

If the line of sight is below 15° with the horizontal, assume that it is at 15°. Assume that the radiation dose within 40° of the line of sight equally distributed throughout the energy spectrum up to 10.8 MeV. If a single energy is desired to characterize this component, a value of about 6 MeV seems reasonable. For the remainder of the radiation, which is markedly scattered, a value of 0.5 MeV appears appropriate.

(c) <u>Neutrons</u>. The following dose angular distribution for neutrons is considered reasonable for ranges of approximately one mile:

> 15% of the flux arrives from directions within an
> angle of 15° from the line of sight;
> 40% of the flux arrives from directions between an
> angle of 15° and an angle of 45° with the line
> of sight;

30% of the flux arrives from directions between
an angle of 45° and an angle of 75° with the
line of sight;

15% of the flux arrives from directions beyond 75°
from the line of sight.

For all directions, one may assume the same energy distribution, that is:

10% of the neutrons have energies over 3 MeV;

10% of the neutrons have energies between 1.5
and 3.0 MeV;

15% of the neutrons have energies between 0.75
and 1.5 MeV;

65% of the neutrons have energies between 200 ev
and 0.75 MeV.

The thermal neutrons are ignored as having negligible biological consequences, compared with the higher energy neutrons.

Since the same energy distribution is assumed for all directions the relationship between biological dose and flux is the same for all directions. If the total biological dose is given therefore for neutrons, rather than flux, the same percentages apply as given above.

It is realized that the estimates given are based on inadequate data. Research is still being conducted on this subject by various groups, and within the next year or two further information should be forthcoming. It is recommended that after this information becomes available and can be used to refine the prompt radiation input data recommended herein, the designs of the entranceways produced from this contract be reviewed to insure that they are neither inadequate nor over-conservative.

5.05 FALLOUT RADIATION

1) Introduction. Chapter IX of Ref. 5.01 is devoted entirely to this subject. The following is only a brief summary of the information contained in that chapter as it applies to the problem of interest of this report.

A shelter located at a range of 4600 ft. from a 1 MT weapon
will be subjected to radiation from the two primary modes of contamination,
i.e., neutron induced activity and fallout. For primarily fission yield
weapons, the contribution through the entrance from the latter source,
at this range, is considerably greater than that from neutron induced
activity.

The amount of contamination and its distribution are dependent
upon many variables, including weapon yield, height of burst,
meteorological conditions, the nature or physical composition of the
surface over which the weapon is detonated, and the relative contributions
of fission and fusion to the total yield. For purposes of this study it
is assumed that the 1 MT weapon is detonated on the surface of the earth
and that fission contributes 100% of the total yield.

These two assumptions are conservative, particularly the latter
since weapons yields of this magnitude usually are fusion weapons triggered
by a fission reaction. However, there are other conceivable cases which
could produce even heavier contamination, e.g., a multiple weapon attack
with overlapping fallout patterns or the detonation of a weapon in a
heavy rainfall.

Brief consideration of the effect of the many variables involved
leads quickly to the conclusion that an infinite number of possible
assumptions can be made. The preceding assumptions, though arbitrary,
are believed to be reasonably, though not excessively, conservative.

2) One-Hour Reference Dose Rate. Based on data obtained at
nuclear weapons tests, a reasonable maximum one-hour reference dose rate
for design purposes is 10,000 roentgens per hour. Paragraph 9.75, Ref. 5.01,
states in part, "Except for isolated points in the immediate vicinity
of ground zero, observations indicate that unit-time reference dose
rates greater than about 10,000 roentgens per hour are unlikely. A possible
reason is that as the weapon yield increases so also does the initial
volume of the radioactive cloud; hence, the maximum concentration of
activity in the cloud does not change very much with the yield. The
fallout contamination moderately near ground zero, where the dose rate
is high, will thus not increase in proportion to the yield, ...".

3) <u>Total Accumulated Dose</u>. Assuming that at this range
(4600 ft) fallout begins to deposit at about one minute after detonation,
the total accumulated dose (for an infinite stay time) at 3 ft. above
the plane of contamination would be 93,000 roentgens. (Fig. 9.20 p. 423,
Ref. 5.01).

4) <u>Energy Spectrum</u>. In order that use can be made of extensive
calculations made by Spencer (Ref. 5.13) and others, it is assumed that
the energy spectrum of the gamma radiation from the contamination is that
associated with fission product decay at about 1 hour after detonation.
It is considered that this is a reasonable approximation to the energy
spectrum over the period of occupancy.

5) <u>Dose-Angular Distribution</u>. Spencer (Ref. 5.13) computed
the dose-angular distribution of gamma radiation emitted by fallout, using
the energy spectrum indicated above, for various cases of interest. These
calculations have been presented in chart form in Ref. 5.13 and will be
used, as appropriate, to determine contributions through the entrance
structures.

5.06 THERMAL EFFECTS

1) <u>Primary Effects</u>. The intensity of thermal radiation at a
range of 4600 ft. from a 1 MT weapon is calculated to be on the order of
1000 calories per square centimeter. This intensity, though high, will
cause no significant damage to exposed concrete portions of the shelter
entrance structure.

However, combustible materials in the vicinity of the shelter
entrance, if ignited, could constitute a serious hazard by producing
noxious gases.

2) <u>Secondary Effects</u>. At this range, the probability of fire
created as an indirect result of the destruction caused by the blast wave
is very high. Whether or not such fires constitute a hazard to the
shelter and its occupants depends upon many factors including the nature
of the construction in the vicinity of the shelter, the distance between
buildings or builtupness of the area, the weather, and the terrain.

Experimental data and a discussion of the environmental hazards
to people in shelters resulting from fires are given in Ref. 5.14. These
data are of importance to the design of the shelter proper and in
particular to the possible requirement for an oxygen supply and chemicals
for removal of carbon dioxide. For underground structures the heat
generated by fires on the surface will not constitute a hazard to sheltered
personnel. Broido and McMasters show that the heat which would "flow"
down an entrance passage would be small compared to the heat generated
by shelter occupants.

The major problem is the oxygen depletion and the buildup of
noxious gases in the air outside. This problem can be solved by providing
means for sealing the shelter and maintaining the quality of the recircu-
lated air inside. The problem can be reduced by locating all entrances,
whether for personnel or ventilation, as far as possible from sources of
fire on the surface of the ground.

　
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TABLE 5.01

RATIO OF HORIZONTAL TO VERTICAL SOIL PRESSURES

Soil Description	K_o, For Stresses Up to 1,000 psi		
	Dynamic	Static	
	Undrained	Undrained	Drained
Cohesionless Soils, Damp or Dry	1/4	1/3-dense 1/2-loose	1/3-dense 1/2-loose
Unsaturated Cohesive Soils of Very Stiff to Hard Consistency	1/3	1/2	1/2
Unsaturated Cohesive Soils of Medium to Stiff Consistency	1/2	1/2	1/2
Unsaturated Cohesive Soils of Soft Consistency	3/4	1/2 to 3/4	1/2 to 3/4
Saturated Soils of Very Soft to Hard Consistency and Cohesionless Soils	1	1	1/2-stiff 3/4-soft
Saturated Soils of Hard Consistency. $q_u = 4$ tsf to 20 tsf	3/4 to 1	1	1/2
Saturated Soils of Very Hard Consistency. $q_u > 20$ tsf.	3/4	1	1/2

TABLE 5.02

SUBGRADE MODULUS

Soil Description	Modulus, k psi per inch deflection
Cohesionless soils	200
Cohesive soils, very stiff to hard consistency	150
Cohesive soils, medium to stiff consistency	100
Cohesive soils, soft consistency	50

TABLE 5.03

SEISMIC VELOCITIES OF VARIOUS SOILS

Soil Type	c(fps)
Loose, dry soils	700 - 3,300
Clays, wet soils	2,400 - 6,400
Coarse, compacted soils	3,000 - 8,500
Cemented soils (Sandstone)	3,000 - 14,000
Shale	6,000 - 17,500
Limestone	7,000 - 21,000
Metamorphic rocks and volcanic rocks	10,000 - 22,000
Sould rocks (Granite)	13,000 - 25,000
Jointed Granite	8,000 - 15,000
Weathered Rocks	2,000 - 10,000
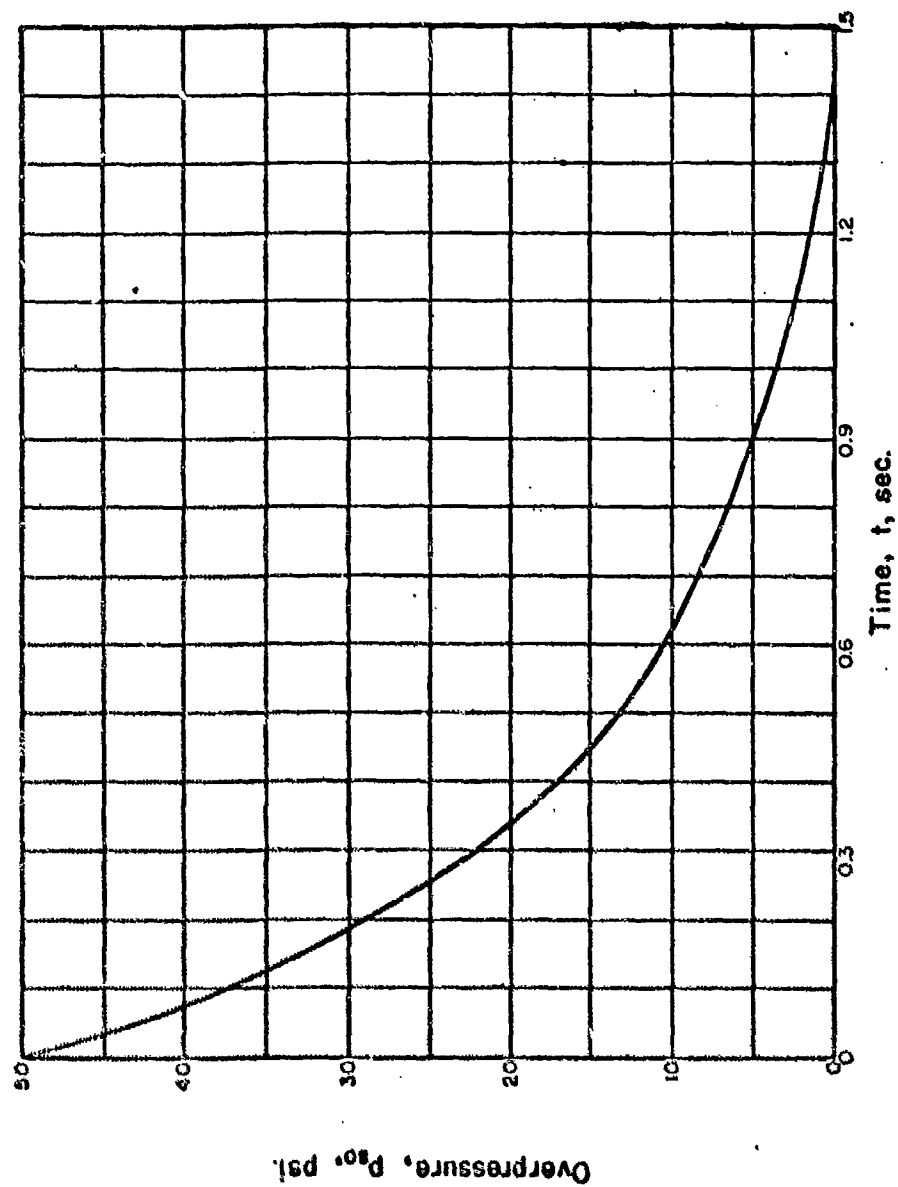
FIG. 5.01 SIDE-ON OVERPRESSURE VERSUS TIME AT 50 PSI FOR 1 MT WEAPON

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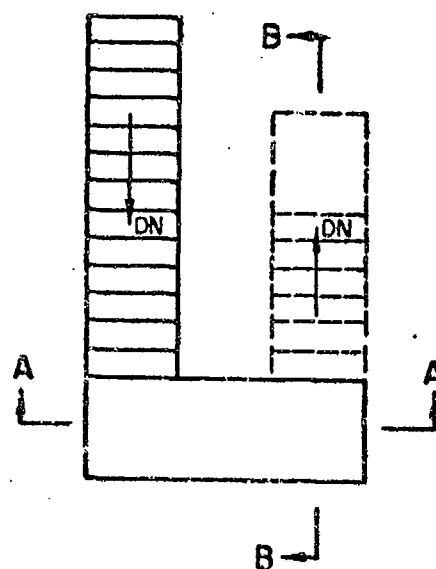
PLAN VIEW
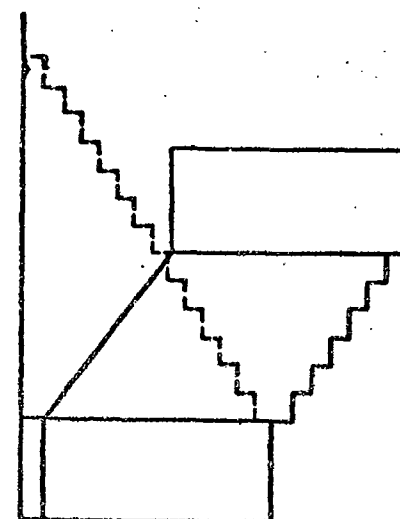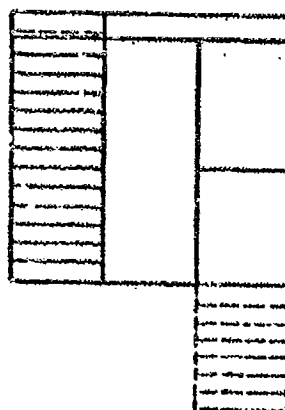
SECTION B-B

SECTION A-A

FIG. 5.02 ASSUMED ENTRANCE CONFIGURATION
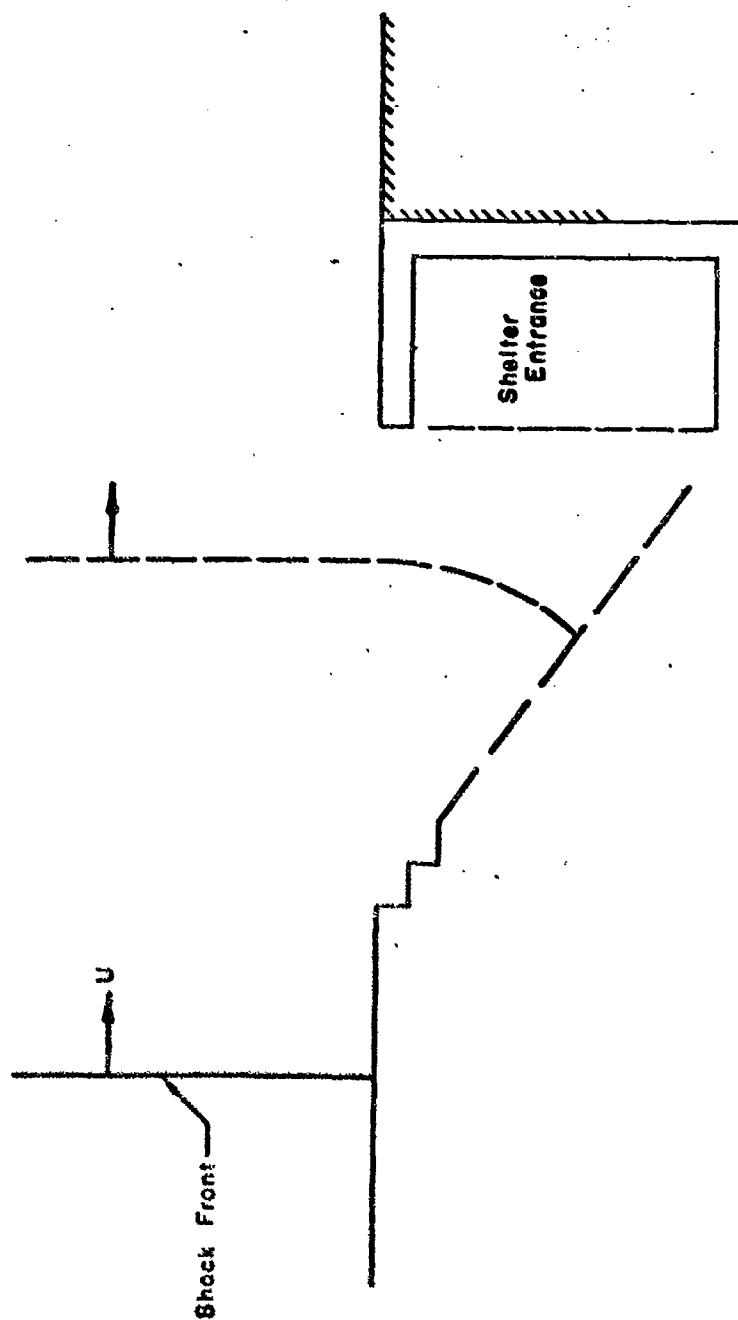
FIG. 5.03 WORST-CASE ORIENTATION FOR SHOCK ENTRY INTO OPEN STAIR ENTRANCE CONFIGURATION

Shelter Entrance

Shock Front

U

116
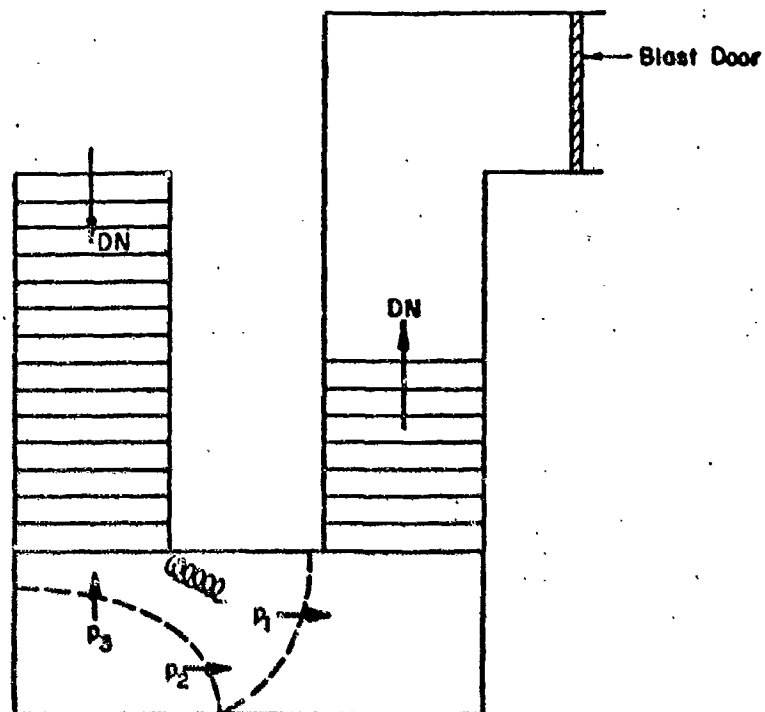
FIG. 5.04 REFLECTED SHOCK PATTERN IN OPEN STAIR

ENTRANCE CONFIGURATION
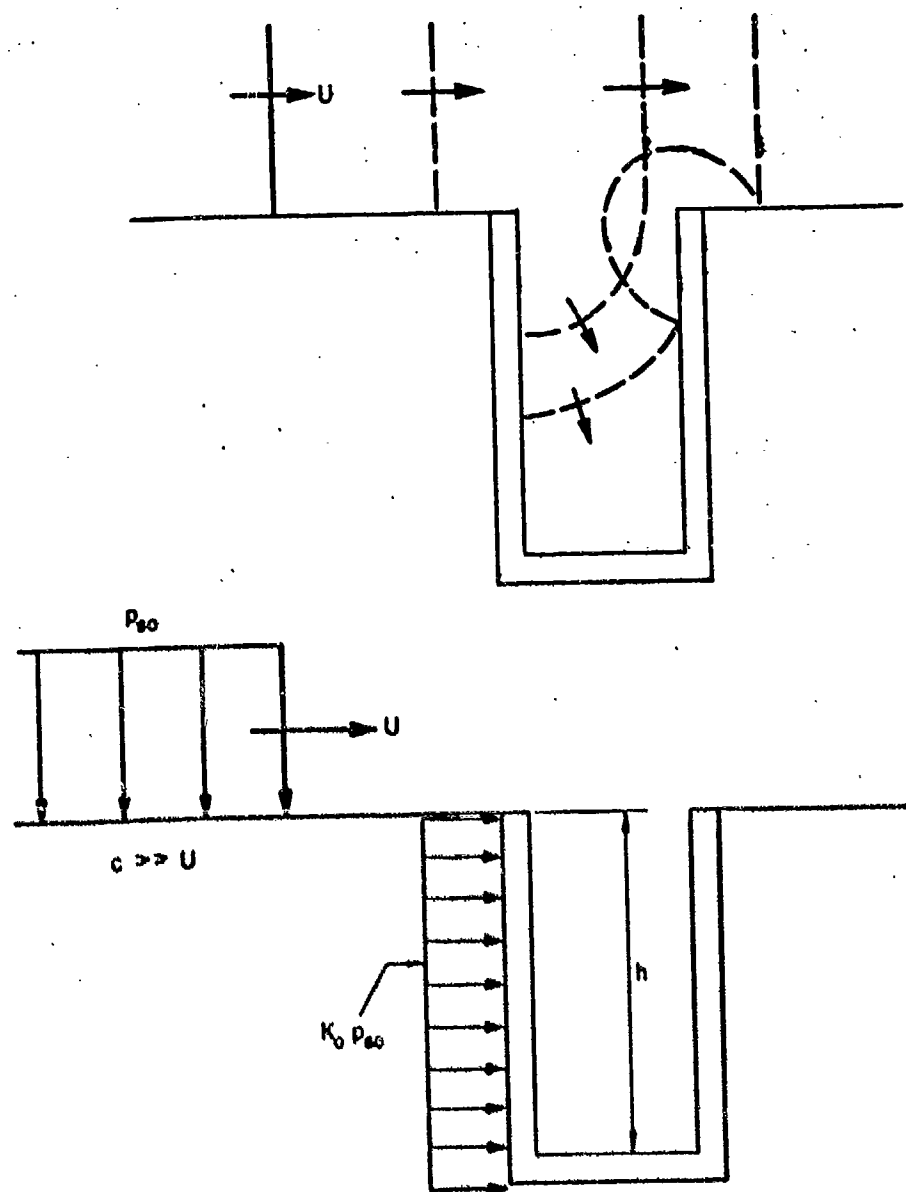
FIG. 5.05   WALLS ADJACENT TO OPEN STAIRWELL

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$$K_p = \frac{1 + \sin\phi}{1 - \sin\phi}$$
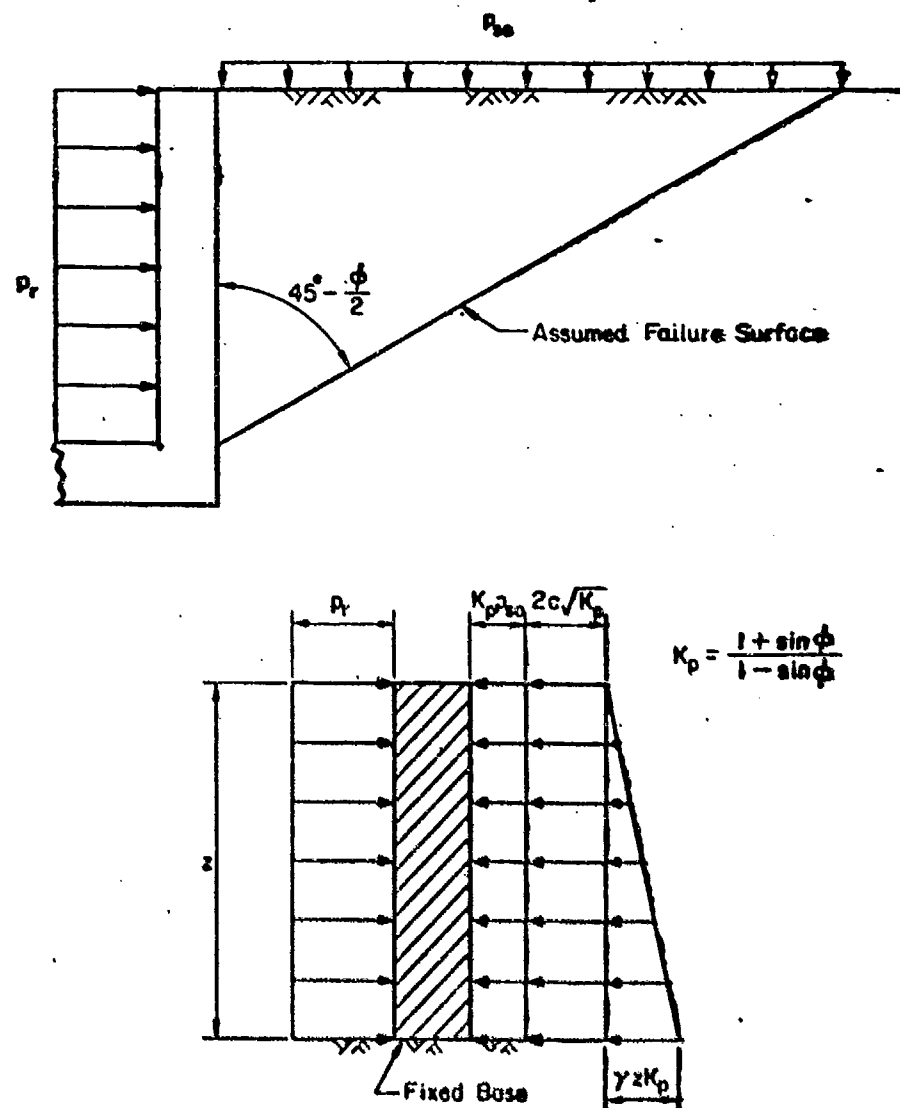
FIG. 5.06 PRESSURES ACTING ON VERTICAL WALL ADJACENT TO OPEN
STAIRWELL-WALL FACING SHOCK FRONT

$$t_r = \frac{b}{U_r}$$

$$t_c = \frac{3b}{U}$$
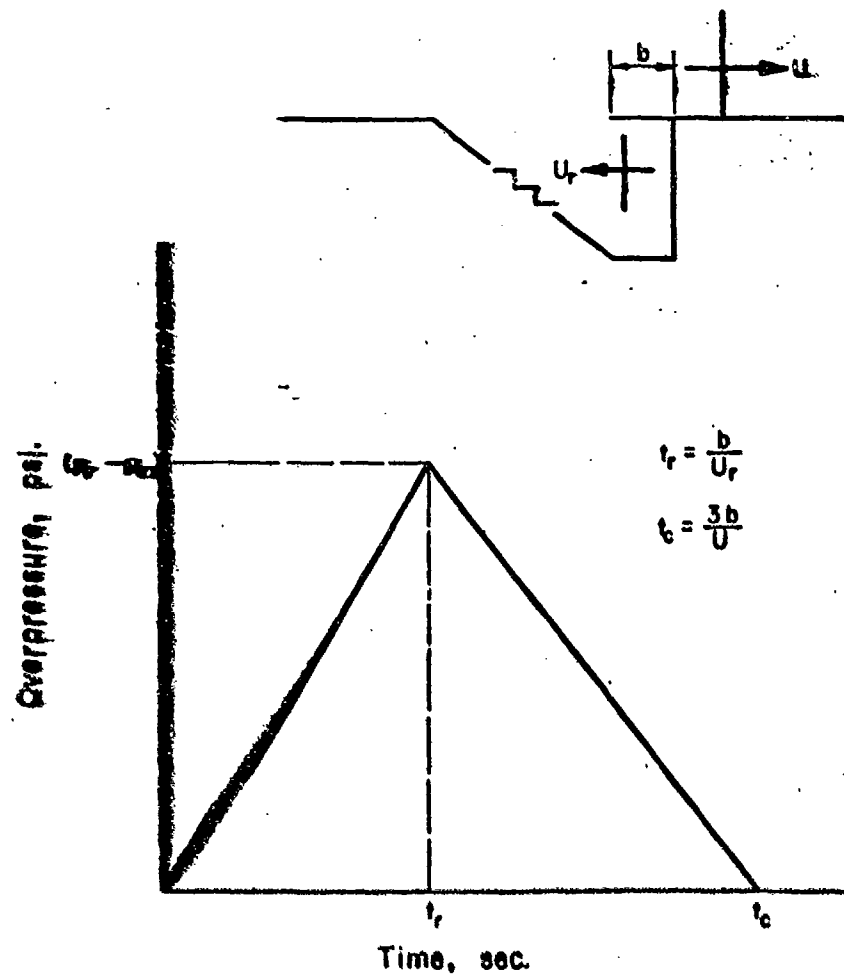
FIG. 5.07 NET LOADING ON SLAB OVER LANDING

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(b) Additional Loading Condition For Case Of
No Blast Door At Outside Entrance.
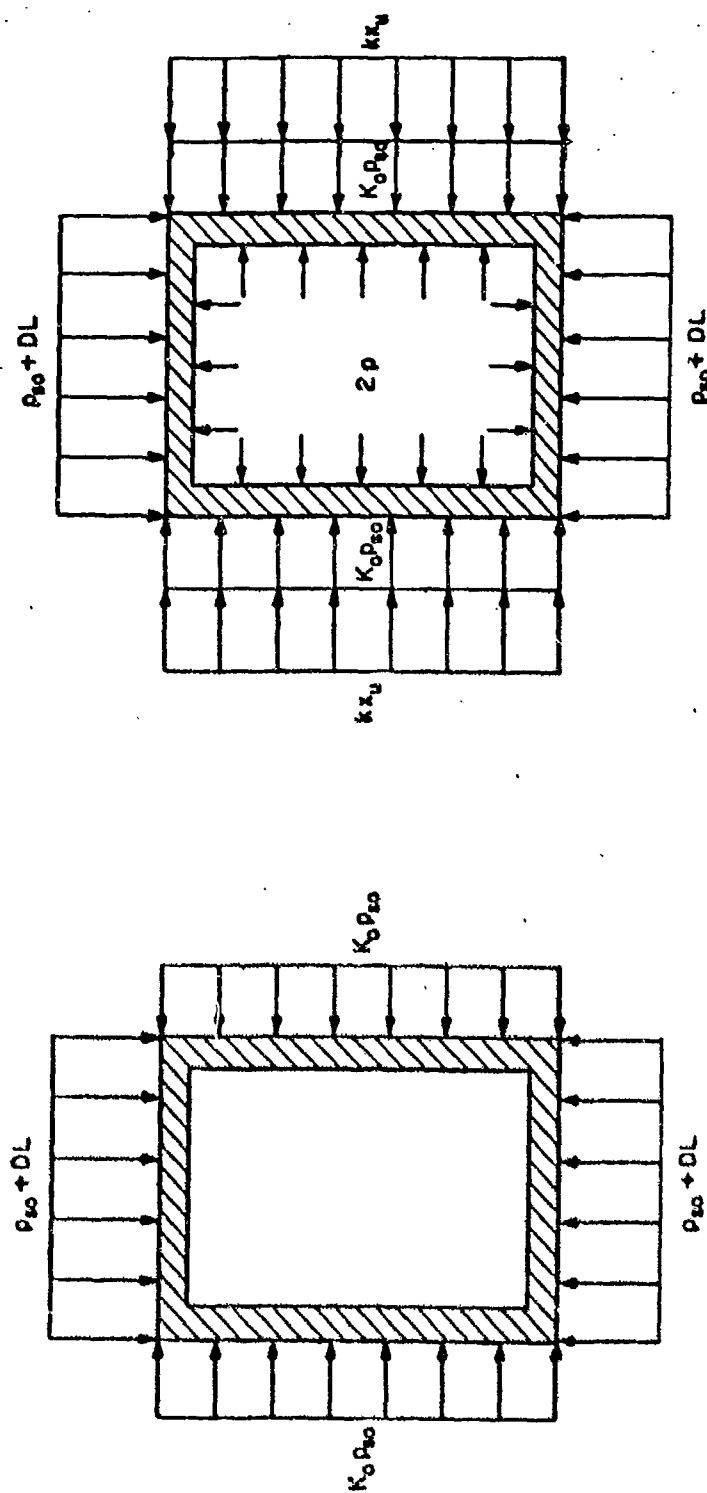
(a) Basic Loading Condition.

FIG. 5.08 SUMMARY OF LOADING CONDITIONS FOR CORRIDOR SECTION BELOW GROUND

Peak Reflected Pressure, P_m, psi.

Angle Of Incidence, α, degrees
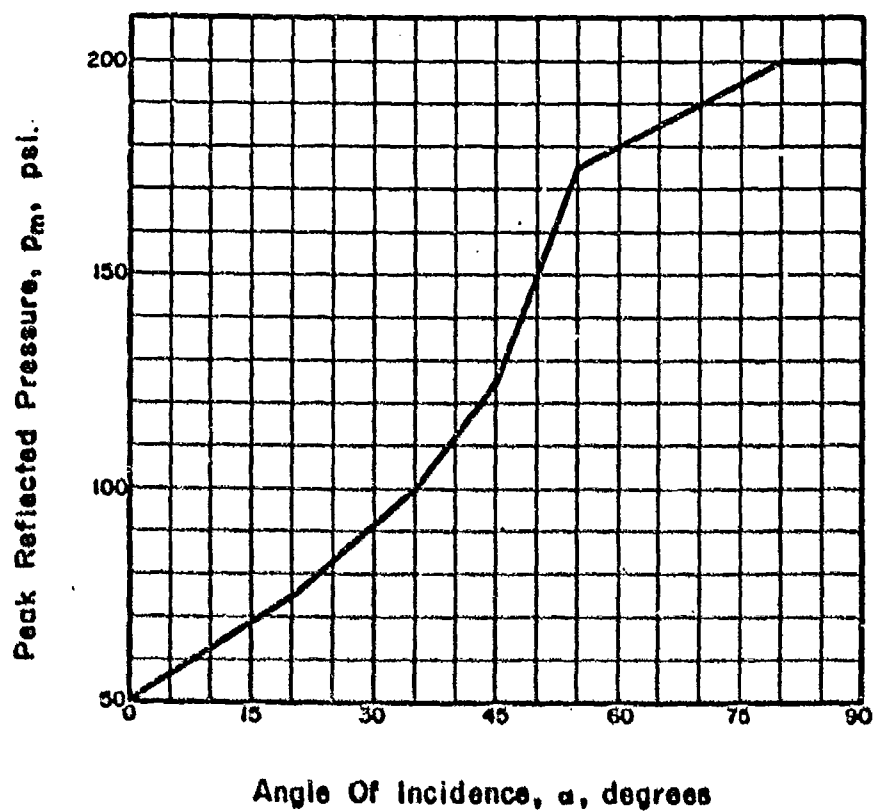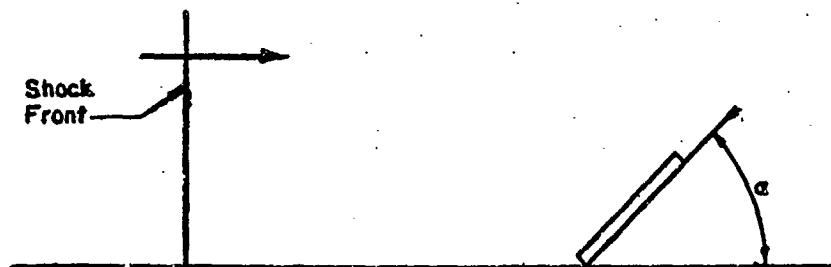
FIG. 5.09   PEAK REFLECTED PRESSURE VERSUS ANGLE OF INCIDENCE FOR

50 PSI SIDE-ON OVERPRESSURE

CHAPTER 6.   RADIATION SHIELDING DESIGN PARAMETERS

6.01   INTRODUCTION

The prime objective of this chapter is to discuss the shielding properties of materials and the radiation protection afforded by the entranceway elements, i.e., entrance opening, corridor lengths and bends, and barriers.

Charts are presented of reduction factor versus solid angle fraction and mass thickness for prompt and residual gamma radiation and for prompt neutron radiation. A detailed design procedure utilizing these charts is presented in Chapter 8.

6.02   PROPORTIONS OF VARIOUS CONTRIBUTIONS

1) Generai. The total dose received within the shelter is the sum of the prompt radiation dose and the residual radiation dose contributed both through the entranceway and through the shelter proper. Therefore, in order to design either of these components the relative proportions of each type of dose must be established.

2) Entranceway vs Shelter Proper. The percentage of the total dose (prompt plus residual) which can be accepted through the entranceway cannot be established a priori. In general form, the relationship between the amount which is contributed through all entranceways and the amount which is contributed through the shelter proper can be expressed as

$$P_f = \frac{1}{R_f} = \frac{1}{C_s + C_e}$$

where P_f = protection factor desired

R_f = reduction factor desired

C_e = contribution through the entrance corridor

C_s = contribution through walls and roof of the shelter

The inter-relationship of C_e and C_s is shown graphically in Fig. 6.01.

When $\frac{C_e}{R_f} = 0$, the mass thickness required in the shelter for a given geometry is a minimum; conversely, when $\frac{C_e}{R_f} = 1$, it is a maximum.

Since this study is devoted exclusively to entranceways and consequently with no prior knowledge of a particular shelter, it has been assumed that half of the total contribution is received through the entranceway and the other half through the shelter proper. Comparative designs for a particular shelter complex may indicate that some other proportion is more economical.

3) <u>Prompt vs Residual</u>. As in the case of proportioning the contribution between the entranceway and the shelter proper, it is difficult to proportion accurately the entranceway contribution between the prompt gamma radiation, prompt neutron radiation and residual radiation before the design of the entranceway. This proportioning will not only be dependent on the relative dose levels of the three types of radiation, but also on the resulting entranceway configuration.

For preliminary design purposes in this study it has been assumed that:

        a. One-half of the contribution through the entranceway is residual radiation.

        b. One-half of the contribution through the entranceway is prompt radiation, divided equally between prompt gamma and prompt neutron.

While this distribution has been used in this report, comparative designs of a complete shelter may indicate that some other proportions are more economical.

4) <u>Proportions Assumed for Design Example</u>. For this study, the following contributions have been assumed in the illustrative design example of Chapter 9:

```
                        Total Dose (40 rads)
                                 |
              _____|_____
             |                                       |
      Shelter Proper                           Entranceway
       (20 rads)                                (20 rads)
             |                                       |
      _____|_____                         _____|_____
     |               |                       |               |
   Prompt        Residual                 Residual         Prompt
                                          (10 rads)       (10 rads)
                                                              |
                                                      _____|_____
                                                     |                 |
                                                  Neutron            Gamma
                                                  (5 rads)          (5 rads)
```
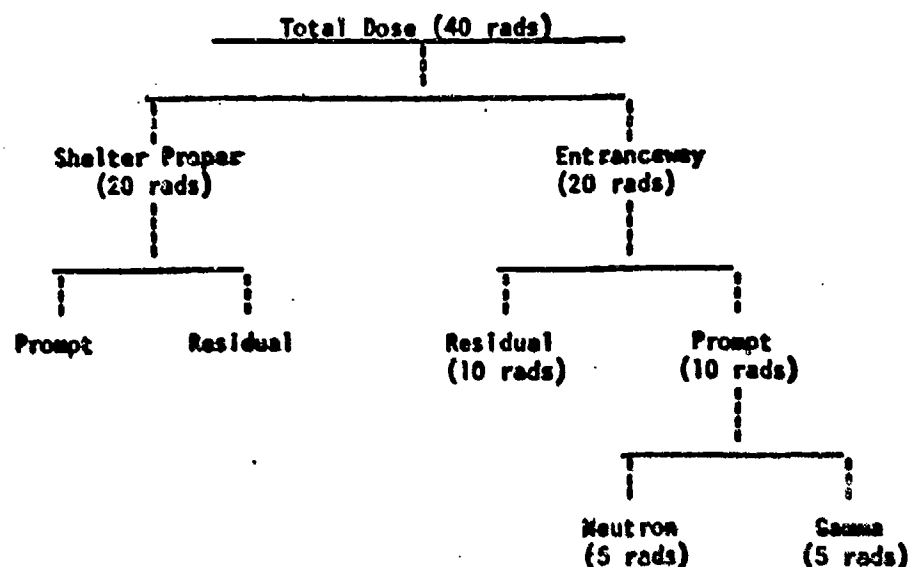
5) _Recommended Procedure._ Based on the above comments, it
is recommended that the following procedure be used.

   a. Determine the acceptable total radiation dose (prompt
       plus residual) which can be tolerated.

   b. Estimate the total radiation dose (prompt plus residual)
       which can be accepted through the entranceway alone.

   c. Estimate the proportions of the entranceway dose which
       will be received from the prompt gamma, prompt neutron,
       and residual gamma radiation.

6.03 SHIELDING PROPERTIES OF MATERIALS

   1) _General._ The shielding properties of various construction
materials are dependent upon many variables, including

   a. the nature of the radiation, i.e., whether particle
       or electromagnetic wave radiation;

   b. the energy of the radiation;

   c. the geometry of the source

   d. the geometry of the shield;

   e. the orientation of the shield with respect to the source;

        f. the physical properties of the elements comprising the
           shield; and

        g. the thickness of the shield.

No simple formulation can cover all cases of interest.

        2) Shielding Against Fallout Radiation. Techniques of shielding
calculations for fallout gamma radiation have been presented by Spencer
(Ref. 6.01). The primary external hazard from fallout contamination is
gamma radiation. For purposes of calculation Spencer used the range of
energies associated with fission product decay at 1.12 hours after detona-
tion and assumed the source distribution to be planar. In addition,
Spencer assumed plane shields of uniform thickness at various orientations
with respect to the source. The results obtained are presented in charts
which may be used for analysis and/or design. Subsequently, these data
were presented in slightly different form in Ref. 6.02. The charts from
the latter reference have been used for all analysis and design work in
this document.

        3) Shielding Against Prompt Nuclear Radiation. Unfortunately
the problem of shielding against prompt nuclear radiation has not been
studied as thoroughly as fallout radiation. The information which follows
is based on preliminary calculations and has inadequate experimental
verification.

        There are two forms of prompt nuclear radiation which are
penetrating and thus hazardous to sheltered personnel; i.e., neutrons
and gamma radiation. A summary of the available information on the
directional and energy distributions of both forms is contained in
Sec. 5.04. The assumed radiation input data presented there are plotted
in Chart 6.01 for both prompt gamma and prompt neutron radiation.

        (a) Shielding Against Prompt Gamma Radiation. As in the
case of fallout gamma radiation, the attenuation of prompt gamma radiation
by a barrier can be expressed as a function of the mass thickness
(X, psf) of the barrier. That is, for most common construction materials,
the same weight per unit area of barrier will reduce the intensity of
radiation by approximately the same amount regardless of the material
used.

Assuming plane shields and broad beam radiation, the effective-
ness of various shield thicknesses may be calculated for various
orientations of the shield with respect to a line from the point of
detonation to the point of interest. In Chart 6.02 the barrier reduction
factor for prompt gamma (nitrogen capture) radiation is plotted as a
function of mass thickness for various orientations of the shield. Since
approximately 85% of the prompt gamma dose at this range is capture gamma
radiation emitted by nitrogen nuclei after capturing neutrons. (Ref. 6.03).
It is conservative to assume that the entire flux is of this higher
energy radiation.

(b) <u>Neutron Shielding</u>. The attenuation of the neutron flux
by a barrier is not so simple. Neutrons may be either scattered or captured
by the nuclei comprising the shield with differing probabilities (cross-
sections) for each of these events and each constituent element of the
shield. Moreover, neutron cross-sections, in general, are quite variable
with neutron energy so that as the neutron loses energy by means of
scattering interactions, the ratio of the scattering and capture cross-
sections does not remain constant.

Fortunately, most soils and ordinary concrete are composed of
much the same elements in roughly the same relative quantities. The two
materials therefore have roughly similar shielding properties.

The attenuation of neutrons from a fission weapon (~ 2.5 MeV)
by a plane shield is plotted in Chart 6.03 as a function of mass thickness
for two orientations. In Chart 6.04 the barrier reduction factor for
neutrons from fusion weapons (~ 14 MeV) is plotted as a function of mass
thickness for two orientations. Note that these charts should be used
only for earth and concrete.

6.04   PROMPT RADIATION PROTECTION

1) <u>Entrance Reduction Factor</u>. The dose received at a point
within the entrance structure will be less than the "free-field" dose
even if the weapon were detonated so that the point of burst could be
seen from this point inside. This reduction is due to the fact that a
portion of the total dose received outside is from radiation which has
been widely scattered.

It is assumed that the contribution inside received from points beyond the field of view is negligible. Of course some portion of that radiation will enter the entrance structure and be scattered from the walls toward the point of interest. Allowance is made for wall scattered radiation in Chart 6.0T.

To obtain the entrance reduction factor, it is necessary to compute the solid angle fraction subtended by the opening at the point of interest and enter the abscissa of Chart 6.01 with that value. The value obtained from the ordinate is the entrance reduction factor.

Appendix C presents a definition and a discussion of the solid angle fraction. For convenience in computing the solid angle fraction subtended by a rectangular surface at the point of interest, the solid angle fraction is plotted as a function of two parameters "e" and "n" in Chart 3 of Ref. 6.02. These parameters are defined in Appendix C.

2) <u>Gamma Attenuation by Bends Beyond Entrance</u>. The reduction factor for bends beyond the first leg of the entrance corridor may be calculated as follows for 90° bends:

(a) <u>First 90° bend</u>.

$$R_{f_1} = 0.1 \, \omega_1$$

where R_{f_1} = reduction factor for first 90° bend beyond the entrance leg

ω_1 = solid angle fraction subtended by the corridor section at the next point of interest

(b) <u>Second and subsequent 90° bends</u>.

$$R_{f_n} = 0.5 \, \omega_n \; ; \; \text{for } n = 2,3...$$

For convenience the solid angle fractions subtended by the standard corridor widths of 3 ft. and 4 ft. and for the standard corridor height of 7 ft. are plotted as function of the corridor length, ℓ, in Chart 6.05.

3) <u>Neutron Attenuation in Corridor Beyond First Bend</u>. There is very little in the way of theory or experiment which bears directly on the

problem of the attenuation of neutrons in the entrance structure. There-
fore, the method of solution offered here is not at all precise. The
approach is based on data obtained by the Armour Research Foundation on
the streaming of thermal neutrons along a two-legged idealized entrance-
way, 6 ft. square. (Ref. 6.04). These data indicate that the attenuation
of thermal neutrons down the second leg follows an exponential law;
furthermore, by extrapolating backward from the second leg into the first
leg, without regard to the turn at the corner, the same exponential
relationship matches the data for the first leg within a factor of two
or better. Qualitatively, these same results have also been obtained
for thermal neutrons streaming through bent cylindrical ducts in reactor
shields (see Fig. 4.12.6 of Ref. 6.05). The exponential relationship
is such that the dose is reduced by approximately a half for every 4.4
ft. of duct length, measured down the center axis of the corridor,
regardless of any turning. It is supposed therefore that this exponential
rule may serve for all neutrons and that the same half length occurs for
every energy group; in other words, the energy distribution of the neutrons
remains essentially constant as it proceeds through the entranceway or,
at least if it does not, it is not too unsafe to assume that it does.

The other supposition is that this attenuation rate scales
directly with the average cross-sectional dimension. It is not unreasonable
to assume that if neutron flux attenuates by neutron collision with the
walls, an equivalent picture can be drawn with corresponding paths at
some other scales. This can be assumed provided corridor cross-sectional
dimensions are large compared with the neutron mean-free-path in the wall.
Thus, the attenuation half-length of a corridor at three-quarters scale
should be three-quarters of that at full scale; or, in terms of corridor
linear cross-sectional dimension, the half-length for attenuation would
be the same number of corridor "diameters" down the corridor regardless
of scale. It is also reasonable to use the average of actual width and
height as an average "diameter" as long as the height-to-width ratio is
not greatly different from unity.

Thus, to obtain a reduction factor for neutrons streaming
down the entrance corridor beyond the first 90° bend, it is necessary to
obtain a "half-length" for the corridor and then to divide the total

length of corridor beyond the first bend by the "half-length" to obtain
the number of "half-lengths" involved.

(a) Half-length.

$$L_{1/2} = \frac{1}{2} (H + W) \left(\frac{4.4}{6}\right) = 0.366 (H + W)$$

where $L_{1/2}$ = half length of entrance corridor, ft.

H = height of corridor, ft.

W = width of corridor, ft.

(b) Number of half-lengths.

$$n = \frac{L}{L_{1/2}}$$

where n = number of half-lengths

L = total length of corridor to point of interest
beyond the first bend.

(c) Reduction factor for neutrons beyond first 90^0 bend.

$$R_{fn} = \frac{1}{(2)^n}$$

4) Attenuation by Barrier Shielding.

(a) Barrier at entrance. When there is a barrier at the
outside entrance the barrier reduction factor is obtained from Charts
6.02 through 6.04 for the appropriate angle of incidence and type of
radiation.

(b) Barriers beyond first 90^0 bend.

1. Gamma Radiation. The energy level of that gamma
radiation which has scattered through an angle of 90^0 cannot be greater
than 0.51 MeV, regardless of the energy of the initial photons. Therefore,
a barrier of a given mass thickness (X) will be more effective for such
scattered photons than for the higher energy photons. A barrier reduction
factor for 0.5 MeV gamma radiation is plotted as a function of mass
thickness in Chart 6.06.

Further scattering will reduce still further the energy level of the radiation. Therefore, it is conservative to use the reduction factor obtained from Chart 6.06 for all barriers beyond the second 90° turn as well.

2. Neutrons. It is probable that the energy spectrum of the neutron flux beyond the first 90° bend will be shifted toward the lower end of the free-field spectrum for many reasons, including the fact that all such radiation must have entered into a scattering interaction and thus has been degraded to a certain extent. In view of qualitative considerations it is probably conservative to use the barrier reduction factor for normal incidence of 2.5 MeV neutrons in Chart 6.03 for all interior barriers.

3. Secondary Gamma Rays. Absorption of thermal neutrons in the walls of the corridor will in general cause secondary gamma rays, which are very likely to create an important hazard, even greater than that caused by the neutrons and gamma rays streaming down from the entrance. At present there is no adequate method of designing against this effect. It is believed that the present degree of conservatism inherent in analysis and design to take care of other hazards will help this situation to some extent, but whether such an approach to the problem is adequate or not is unknown at this time. It has been suggested that introduction of boron into the walls, perhaps by a sort of "wash" of borax or similar material, will help in alleviating the secondary gamma ray problem.

6.05 RESIDUAL RADIATION PROTECTION

1) Entrance Reduction Factor. As in the case of prompt radiation, the dose received at a point inside the entrance structure will be less than that which would be received in the open. The total dose received at such a point is the sum of contributions received from "skyshine"; contamination on an overhead barrier, if any; and contamination on stairs or any other horizontal surface below the point of the detector (called "ground direct").

The procedures for the calculation of the contributions from these sources are presented in detail in Ref. 6.02 and will not be presented

here. The contribution from the skyshine may be obtained from Case 3, Chart 10 of Ref. 6.02, assuming that the dose-angular distribution of skyshine is constant. As an alternative procedure the skyshine contribution could be obtained from Chart 5, Ref. 6.02. The contribution from contamination on an overhead barrier may be obtained from Chart 4 of the same reference. And, finally the ground direct contribution from plane sources below the level of the detector may be obtained from Chart 5 by treating each such plane as a limited plane source.

2) <u>Attenuation by Bends Beyond Entrance</u>. The procedures for calculating the residual radiation dose reduction by bends beyond the first leg of the entrance corridor are identical to those given in Sec. 6.03 for prompt gamma radiation.

3) <u>Attenuation by Barrier Shielding</u>.

(a) <u>Horizontal Barriers at Outside Entrance</u>. If there is a horizontal barrier covering the outside entrance, the reduction factor should be obtained as indicated above from Chart 4 of Ref. 6.02. That is, this barrier reduction factor will be handled as a part of the entrance reduction factor.

(b) <u>Vertical Barriers at Outside Entrance</u>. The barrier reduction obtained by a vertical barrier at the outside entrance can be obtained from Case 2, Chart 1 of Ref. 6.02. Note that the installation of such a barrier could increase the dose received at a point below the plane of contamination outside by scattering ground direct radiation down to the point of interest. If such a barrier is provided it should have a mass thickness in excess of 50 psf.

There are two cases of interest here which should be handled differently.

1. <u>Detector Above Plane of Contamination (See Fig. 6.02)</u>. This case should be treated in the conventional fashion assuming the door to be an exterior wall. Thus the contribution through the vertical door only (to which the contributions from other sources should be added) may be written:

$$C_d = \frac{\alpha}{360^\circ} \; B_d(X_d) \left\{ \left[G_a(\omega_u) + G_d(\omega_\ell) \right] \left[1 - S_d(X_d) \right] \right.$$
$$\left. + \left[G_s(\omega_u) + G_s(\omega_\ell) \right] \left[S_d(X_d) \right] \left[E(e) \right] \right\}$$

where C_d = contribution through the door,

           α = angle subtended by the door in the horizontal plane,

           $B_d(X_d)$ = barrier factor (function of the mass thickness of the door) obtained from Case 2, Chart 1, Ref. 6.02,

           $G_a(\omega_u)$ = skyshine contribution (function of the upper solid angle fraction) obtained from Chart 5, Ref. 6.02,

           $G_d(\omega_\ell)$ = ground direct contribution (function of the lower solid angle fraction) obtained from Chart 5, Ref. 6.02,

           $S_d(X_d)$ = scatter factor (function of the mass thickness of the door) obtained from Chart 7, Ref. 6.02,

           $G_s(\omega_u)$ = wall scattered contribution received through the upper solid angle fraction, obtained from Chart 5, Ref. 6.02,

           $G_s(\omega_\ell)$ = wall scattered radiation received through lower solid angle fraction, obtained from Chart 5, Ref. 6.02

           $E(e)$ = shape factor (function of the eccentricity ratio) obtained from Chart 8, Ref. 6.02.

           (Note: $e = \frac{W}{L}$)

2. **Detector Below Plane of Contamination (See Fig. 6.03).**
Assuming the detector to be located above the landing, the contribution
received through the door at this point may be written:

$$C_d = \frac{\alpha}{360^\circ} \; B_d(X_d) \left\{ \left[G_a(\omega_u) - G_a(\omega_u') \right] \left[1 - S_d(X_d) \right] \right.$$
$$\left. + \left[G_s(\omega_u) - G_s(\omega_u') \right] \left[S_d(X_d) \right] \left[E(e) \right] \right\}$$

The notation is as indicated in Fig. 6.03 and the procedure is
the same as indicated for the case of the detector above the plane of
contamination.

(c) <u>Barriers Beyond First 90° Bend.</u> The attenuation of
fallout gamma radiation by barriers beyond the first 90° bend will be
handled in exactly the same fashion as for prompt gamma radiation. It
is apparent that a barrier inside will be more effective, pound for
pound, than an exterior barrier, solely because the energy of the gamma
radiation has been degraded by scattering interactions within the
corridor.

6.06 RECENT EXPERIMENTAL EVIDENCE

Recent experiments indicate that for fallout radiation the factor
by which the solid angle fraction of the first bend is multiplied to obtain
the corridor reduction factor may be substantially greater than 0.1,
possibly as high as 0.2 or 0.3. On the other hand, indications are that
the 0.5 for the subsequent bends may be overly conservative. However,
since the albedo for the more energetic prompt gamma radiation is
smaller than for fallout gamma radiation, it is quite likely that the 0.1
factor for the first bend is adequate for the prompt gamma radiation.

However, in order to have the design procedure and illustrative
problem conform to the methodology of Reference 6.02, the multiplying
factors of 0.1 for the first bend and 0.5 for subsequent bends have been
utilized herein.

6.07 REFERENCES

6.01 Spencer, L. V., "Structure Shielding Against Fallout Radiation from Nuclear Weapons," U. S. Department of Commerce, National Bureau of Standards, NBS Monograph 42, June 1, 1962.

6.02 Office of Civil Defense, "Design and Review of Structures for Protection from Fallout Gamma Radiation," Revised 1 October 1961.

6.03 FitzSimons, Neal, "Integrated Design for Comprehensive Protection from the Effects of Nuclear Weapons," Office of Civil and Defense Mobilization, Washington 25, D. C., Review Draft December 27, 1960.

6.04 Terrell, C. W. and Jerri, A. J., "Radiation Streaming in Shelter Entranceways," Armour Research Foundation Report ARF 1158401-5, July 1961.

6.05 Price, B. T. et al, "Radiation Shielding," Pergamon Press, London, 1956.
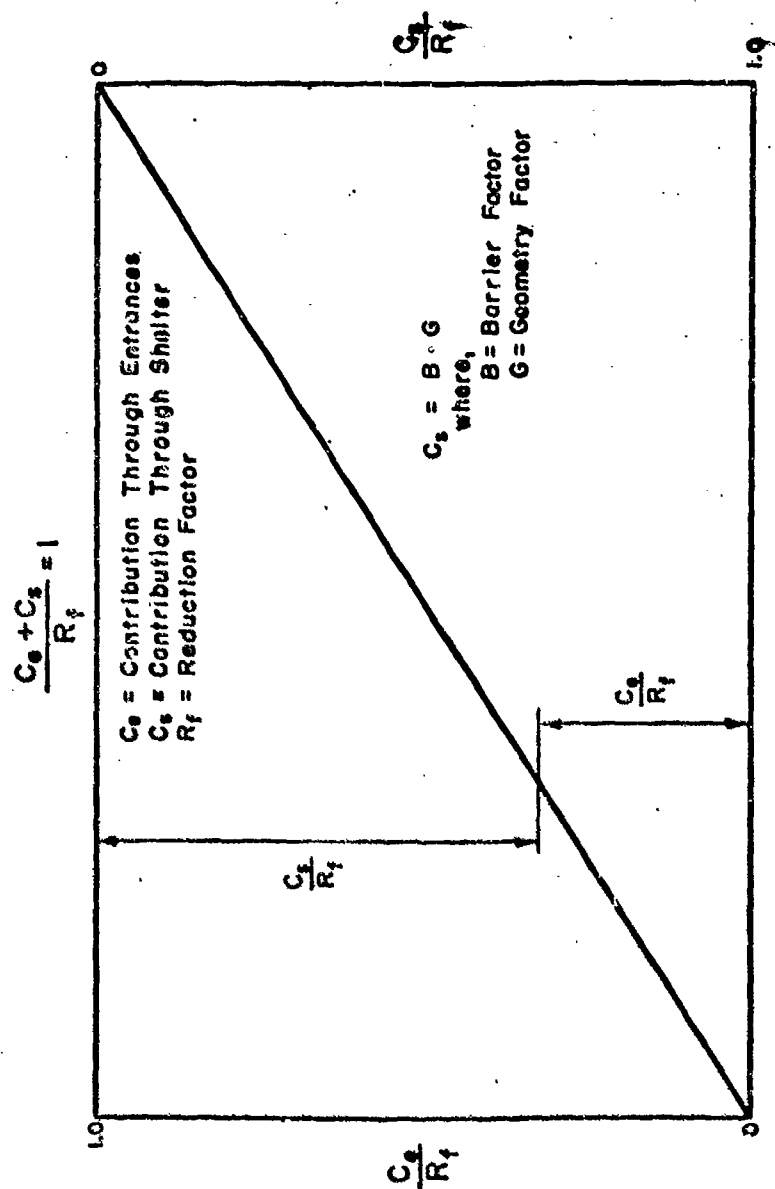
FIG. 6.01 RELATIONSHIP BETWEEN CONTRIBUTIONS THROUGH ENTRANCES AND SHELTER

PROPER FOR GIVEN REDUCTION FACTOR
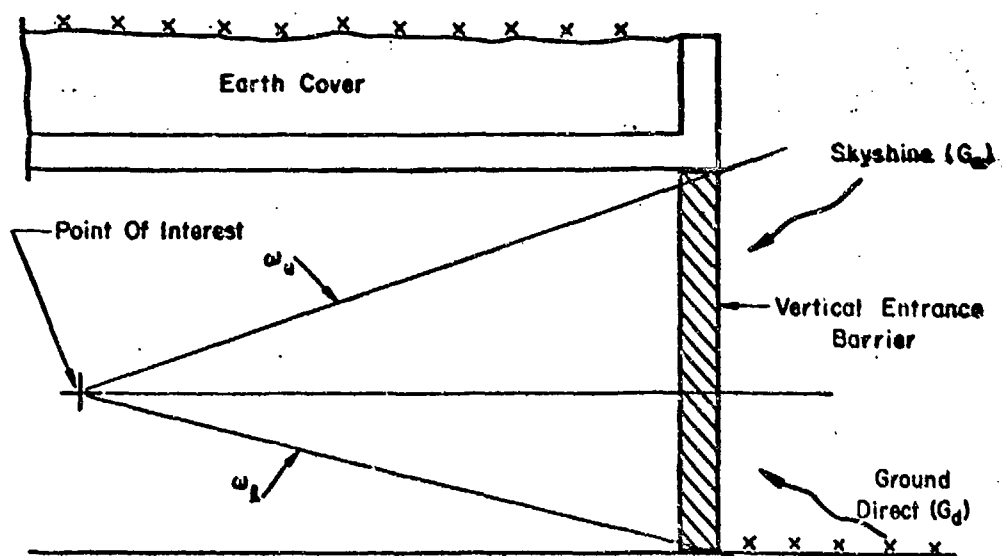
VERTICAL SECTION
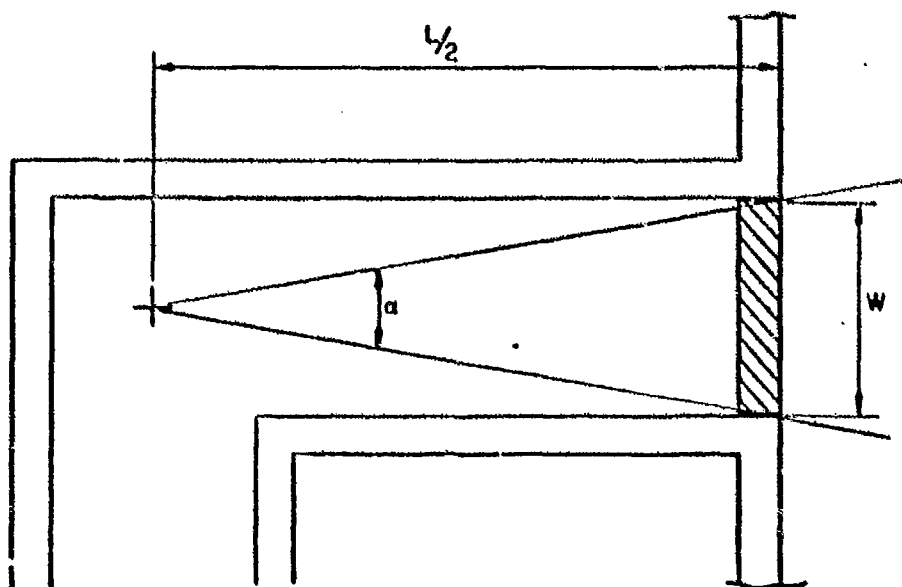
PLAN SECTION

FIG. 6.02   CONTRIBUTION THROUGH VERTICAL EXTERIOR BARRIER (POINT OF
INTEREST ABOVE PLANE OF CONTAMINATION OUTSIDE)

138
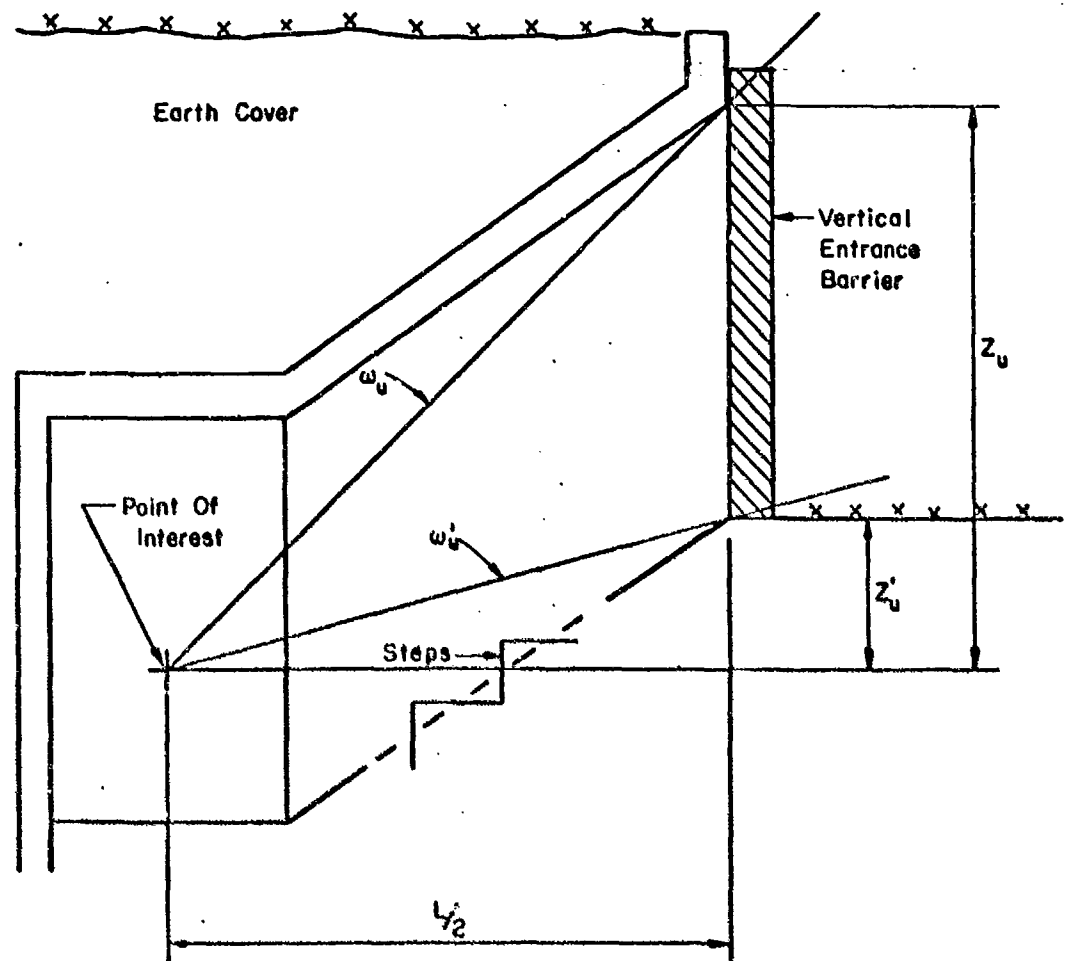
FIG. 6.03 CONTRIBUTION THROUGH VERTICAL EXTERIOR BARRIER (POINT
OF INTEREST BELOW PLANE OF CONTAMINATION OUTSIDE)
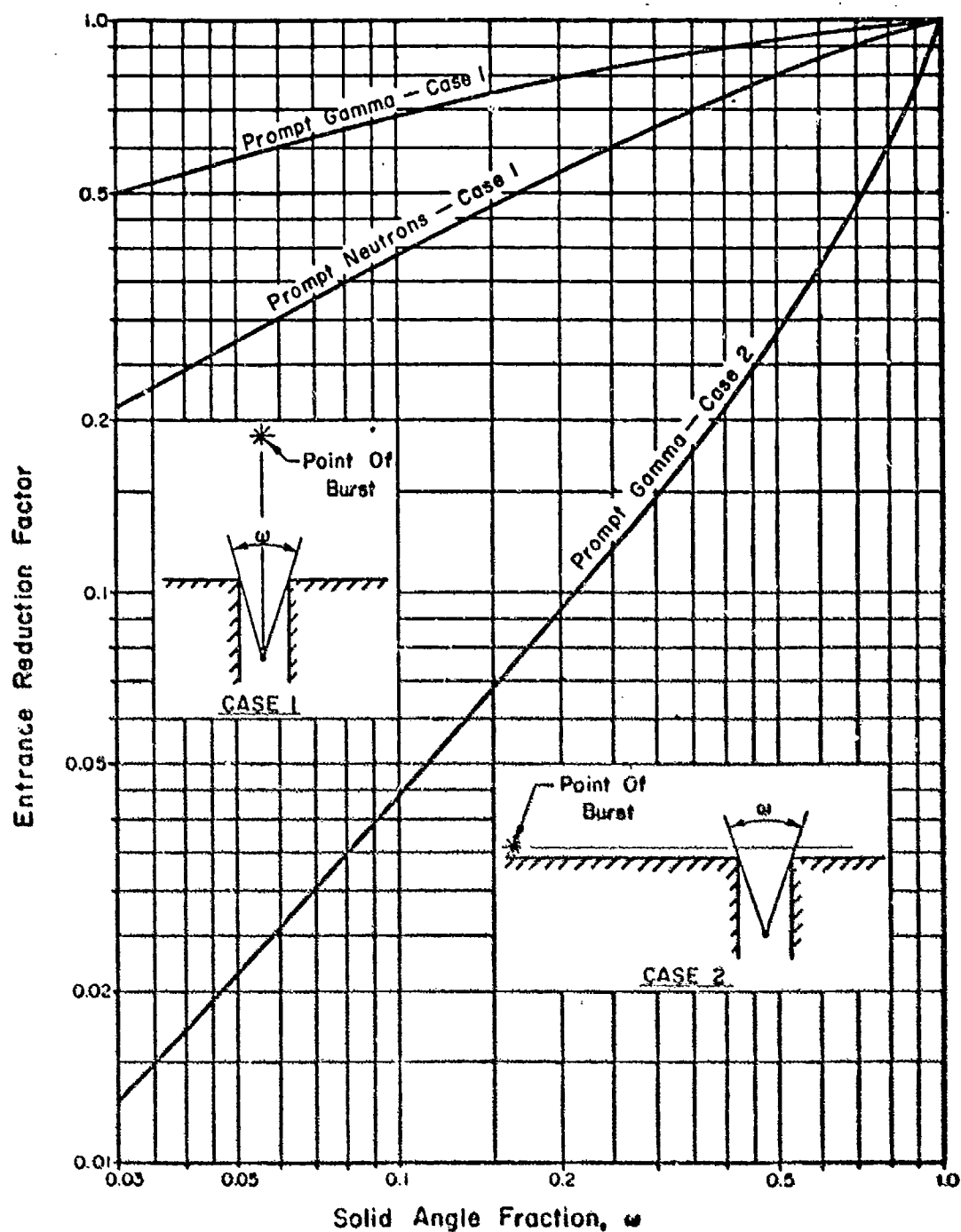
CHART 6.01 ENTRANCE REDUCTION FACTOR FOR PROMPT NUCLEAR RADIATION VERSUS
SOLID ANGLE FRACTION AT A RANGE OF APPROXIMATELY ONE MILE FROM BURST POINT
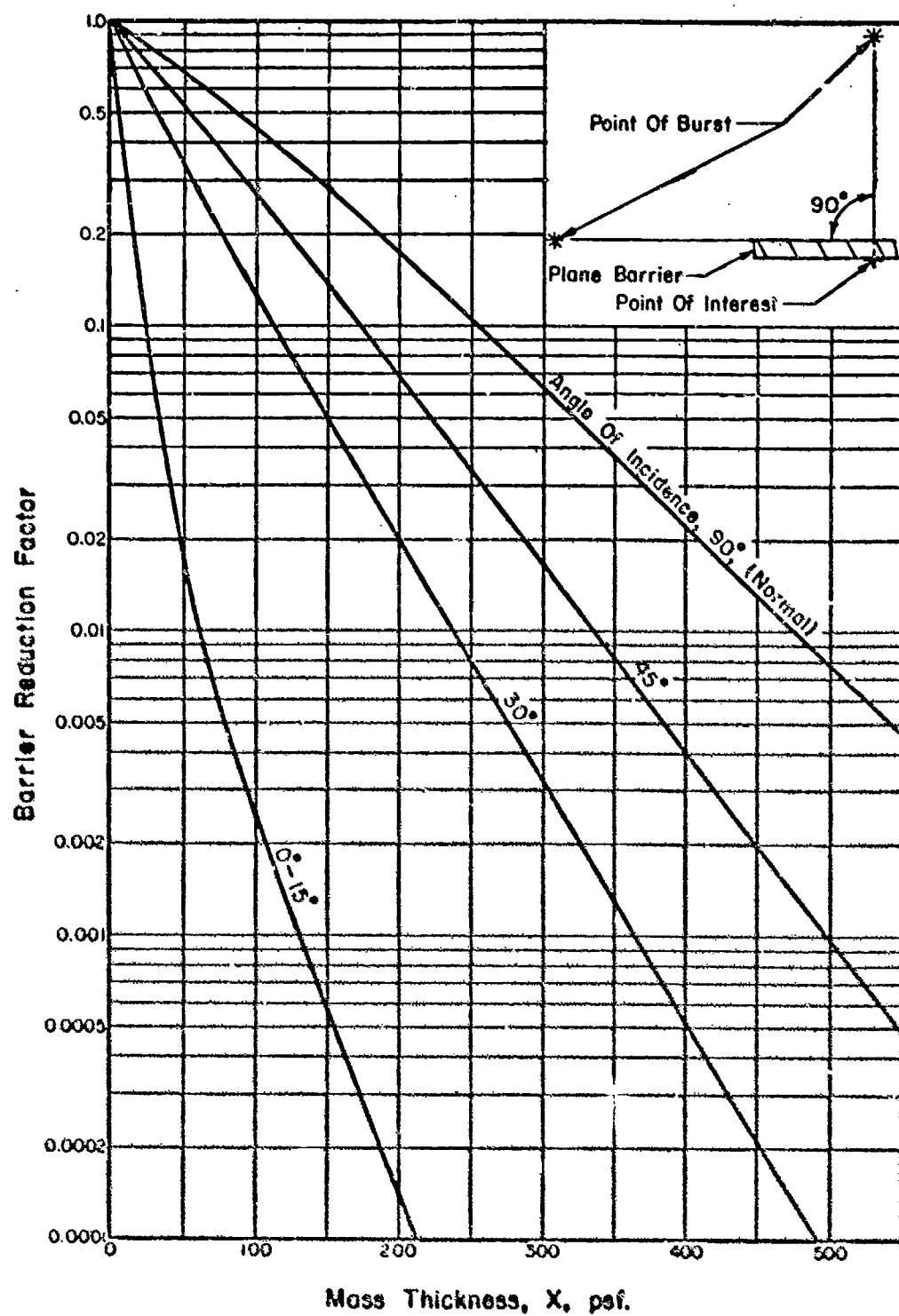
CHART 6.02 BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR

NITROGEN CAPTURE-GAMMA RADIATION

NOTE: Curves Applicable To Earth And Concrete Barriers Only.

CHART 6.03 BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR
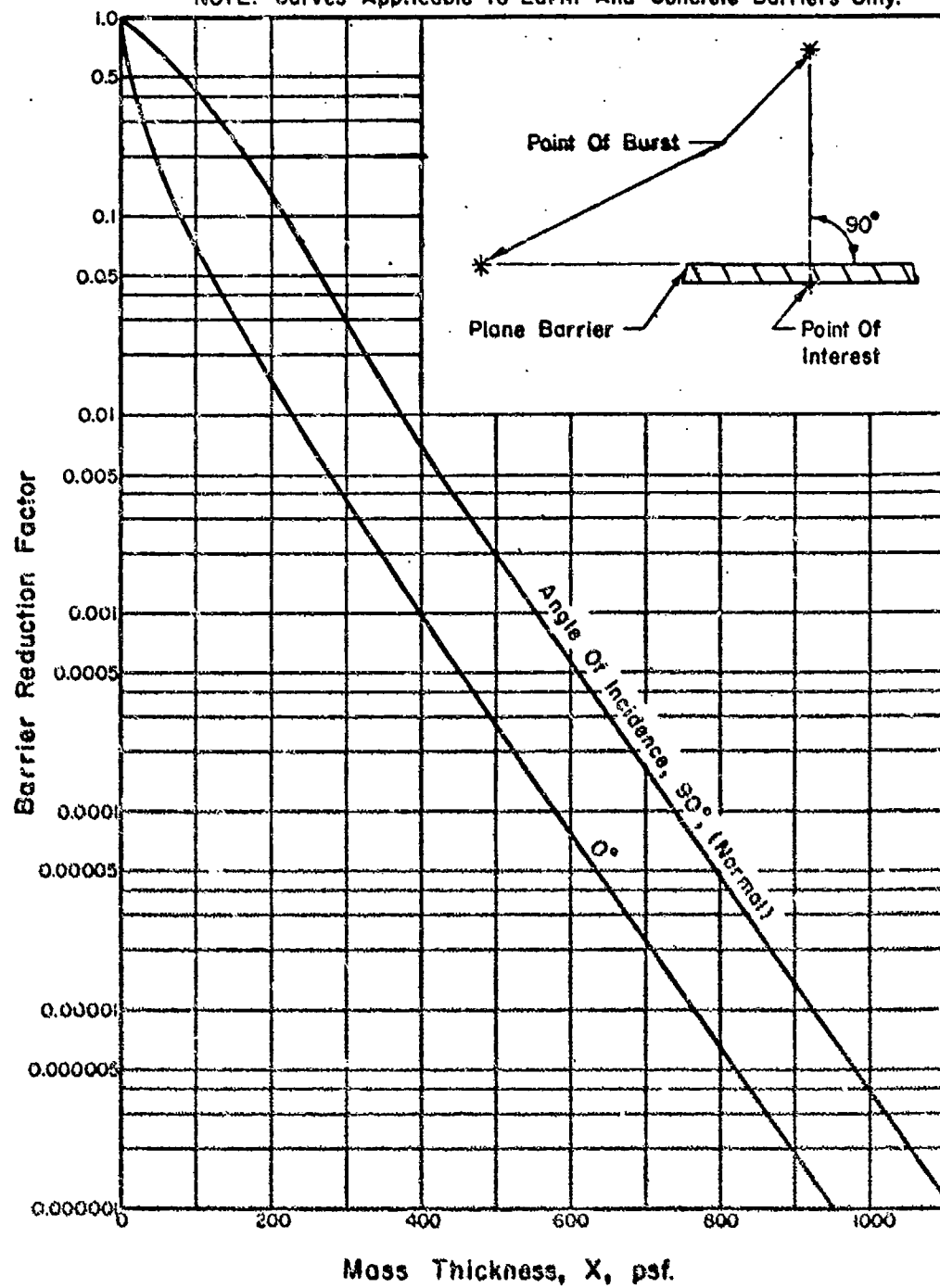
2.5 MEV NEUTRONS

CHART 6.04   BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR

14 MEV NEUTRONS
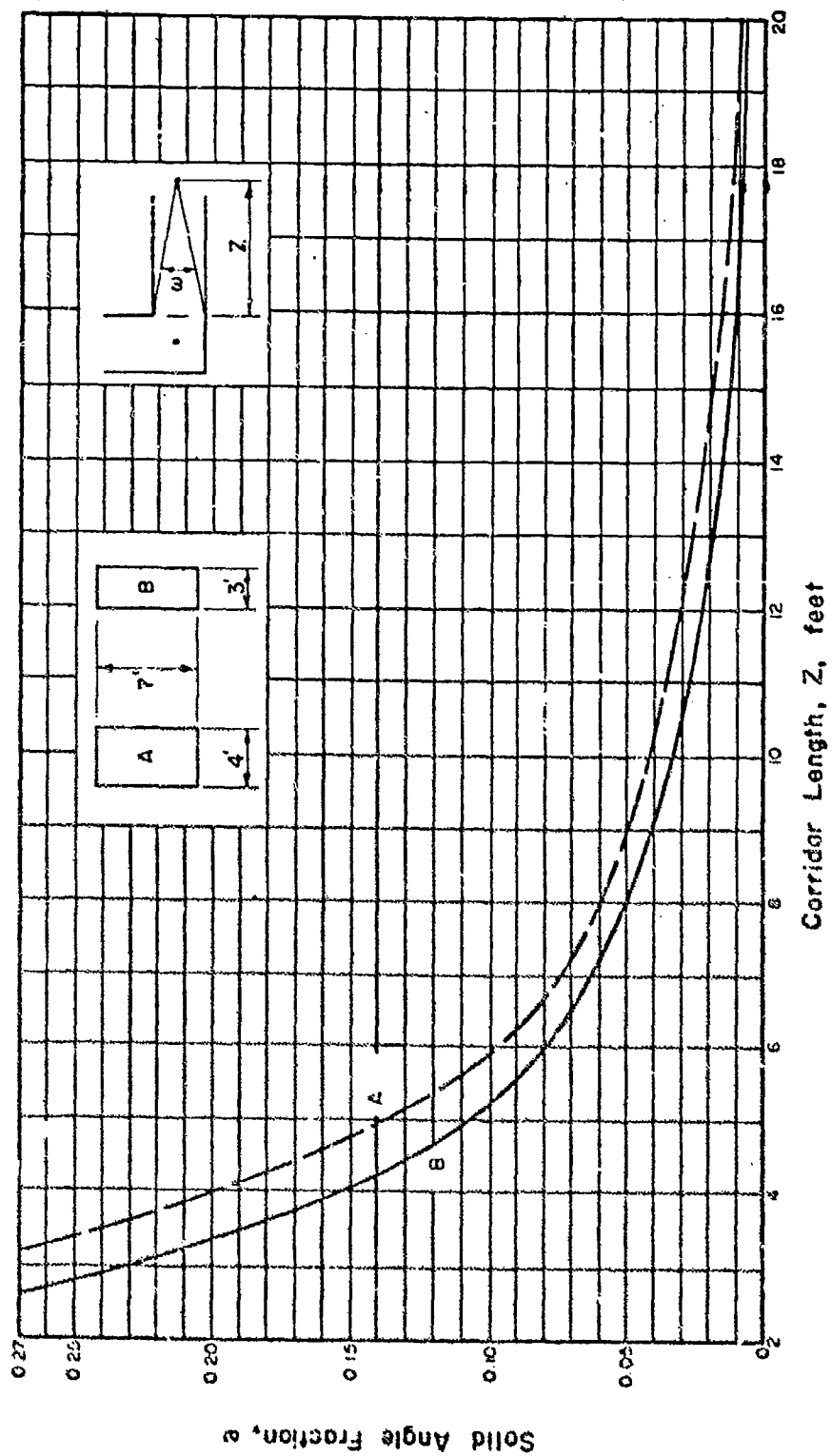
Chart 6.05 Solid Angle Fraction Subtended at Point of Interest for Two Standard Corridor Dimensions as a Function of Length of Corridor

143

NOTE: Use Only For Interior Barrier
Beyond At Least One 90° Turn.
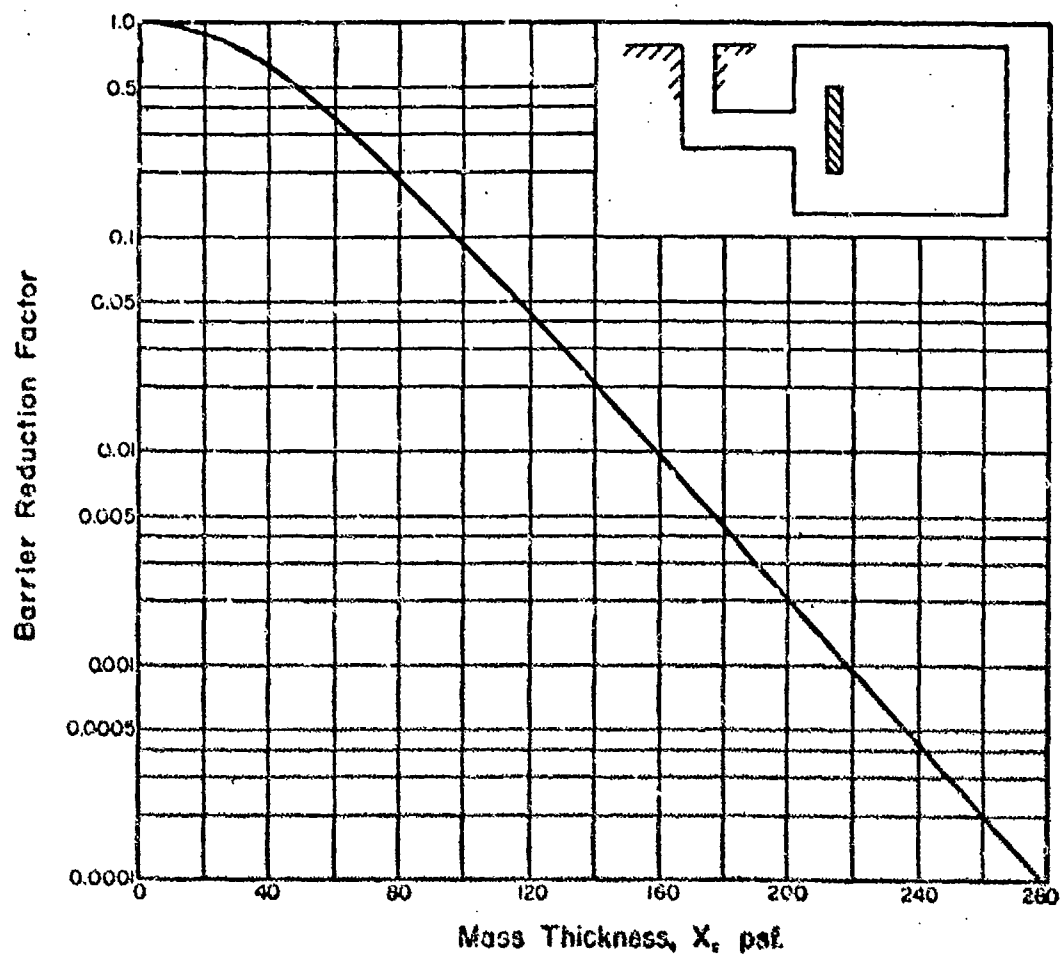
CHART 6.06 BARRIER REDUCTION FACTOR VERSUS MASS THICKNESS FOR

0.5 MEV PHOTONS

CHAPTER 7. BLAST RESISTANT DESIGN PARAMETERS

7.01 INTRODUCTION

In this chapter, the various factors governing the structural design for blast resistance are first discussed. These factors include loading, structural resistance, design considerations as affected by the material used, and the structural properties of these materials. A tabulation of resistance expressions for different materials and support conditions is then presented. Finally, a series of charts for the various materials and support conditions have been included to facilitate the selection of the structural section. Detailed design procedures utilizing these charts are presented in Chapter 8.

7.02 LOADING

The loading of the various structural elements of the entrance-way structure are discussed in detail in Chapter 5. The loads assumed therein are used as the inputs in the design of the structural elements. These loadings (Fig. 7.01) are long duration step pulses with pressures p_m which are a function of the location of the elements and their orientation with respect to the blast wave.

7.03 STRUCTURAL RESISTANCE

1) <u>Yield Resistance</u>. For the long duration step pulse loading shown in Fig. 7.01, the relationship between the design parameters is

$$p_m/q_y = 1 - \frac{1}{2\mu} \qquad \text{(Eqn. 7.01)}$$

where p_m = peak pressure

q_y = the yield resistance of the structural element

μ = the ductility factor defining the maximum acceptable response of the structure, i.e., the ratio of the maximum deflection to the yield deflection

Two important design parameters do not appear in the above equation. These parameters are the measure of the duration of the loading (t_d) and the period of the structural element (T). These parameters do not appear

because the ratio t_d/T is considered to be infinite, or effectively greater than about 3. Ref. 7.01 or 7.02 may be consulted to obtain the relationships replacing the above equation when the ratio t_d/T is small.

The structural yield resistance, q_y, and the limit of acceptable structural response, μ, are determined by considering the resistance-deflection curve for the structural element. The resistance, q, considered as a static loading distributed spatially in the same manner as the air blast loading, is plotted in Fig. 7.02 as the ratio q/q_y, where q_y is the yield resistance. The deflection is also plotted in dimensionless form, x/x_y, where x_y is the yield deflection. The ductility factor, μ, equals x_{max}/x_y, where x_{max} is the maximum acceptable deflection. In the selection of x_{max}, both structural integrity and structural function should be considered. The value of x_{max} should not be greater than the deflection at which the resistance of the structure begins to drop off or fracture occurs. Operational requirements, e.g., avoidance of jamming of a door or its operating mechanism, may set a lower limit on x_{max}.

Fig. 7.02 is a typical resistance-deflection curve with its idealized bi-linear representation as used in design. The idealized resistance function is constructed so that the area under both the real and ideal curves are equal at yield and at maximum response.

The design involves establishing the required yield resistance for the structural element and then providing this resistance in the structural element. The peak pressure, p_m, is evaluated using the blast input data presented in Chapter 5 and the reflection factor which is a function of the orientation of the structural element with respect to the blast wave. If allowable maximum deflection is set by structural considerations, the ductility factor, μ, is a function of the type of structural element and the materials used. If operational requirements govern, the ductility factor, μ, will be selected to limit the maximum deflection of the structure to the permissible magnitude.

In the Sec. 7.06, expressions are presented for the yield resistance (q_y), the yield deflection (x_y) and the period (T) for door elements of various materials and structural types. The maximum recommended value of the ductility factor based on consideration of structural

Integrity is presented for each material and each structural type considered. These μ values must then be checked to insure that the resulting deformations are operationally acceptable.

2) <u>Rebound Resistance</u>. All structures designed to resist blast forces must be proportioned to provide rebound resistance, which is equivalent to resistance to forces acting opposite to the direction of the air blast loading. Rebound behavior is most severe in situations in which the air blast is sharply peaked, but appreciable rebound can also occur for long duration loadings. The required rebound resistance as a function of μ and the ratio of loading duration to period (t_d/T) can be found from procedures given in Ref. 7.01 or 7.03. A rebound resistance of $q_y/2$ is adequate for peak pressures, p_m, of 100 psi or less, i.e., for the design of door structures that are located either flush with the ground surface and not subjected to a reflected pressure spike or at the end of an entranceway. A rebound resistance equal to q_y is always adequate. If it is difficult or expensive to provide these levels of rebound resistance, see Ref. 7.01 or 7.03 to determine whether a lower level of rebound resistance is adequate for the design loading condition.

7.04 DESIGN CONSIDERATIONS

1) <u>General.</u> Presented herein are design considerations such as recommended ductility factors, stability requirements, reinforcing percentages, etc.

2) <u>Design in Metals</u>. Door designs in structural steel or aluminum are based on plastic design principles. For members responding primarily in flexure, if the sections are sufficiently ductile to permit redistribution of moment after the first inelastic action begins, the yield moment is taken as the fully plastic moment of the cross-section.

Structural carbon steel, i.e., ASTM A-7, A-36, or A-373, possesses a high degree of ductility and strain hardens markedly. Therefore, the zones of inelastic behavior in structural elements formed of these alloys will be widespread. A ductility factor in flexure of 10 has been used for the design in these alloys.

Higher strength steels and tempered aluminum alloys have less ductility and strain harden less than the above mild steels. The zones of inelastic behavior will be more limited in extent with limited plastic hinge rotational capacity. Therefore, a ductility factor of no more than 3 is recommended for designs of flexural members in these materials.

Compression members should be designed for a ductility factor of 1.3. Tension members may be designed with the ductility factor appropriate for the material in flexure.

In order that the yielded cross-section of a member continue to transmit the fully plastic moment through large rotations of the plastic hinge, limitations are placed on the cross-sectional dimensions to insure stability against buckling. Two types of instability are important for flexural members: (1) local buckling of elements of the section, and (2) lateral buckling of the compression flange. Lateral buckling is not commonly a problem for door elements since the compressive flanges will ordinarily have continuous lateral support. However, in instances where compression flanges are unsupported, the stability of the member should be evaluated following the procedures given in Ref. 7.04 for steel, and in Ref. 7.05 for aluminum. It is noted that tests have shown a lessened tendency towards buckling for rapid load application; therefore, the usual specified minimum values for yield stress may be used as the required stress level in equations for stability.

The following limitations on the dimensions of 6061-T6 aluminum sections were obtained from the equations given in Ref. 7.05. The critical stresses were taken as the appropriate specified minimum yield stresses. Interaction equations are given in Ref. 7.04 for states of stress more complex than those indicated.

Stability Requirements for 6061-T6 Aluminum Alloy Sections

Compression flange of WF, I or H section $\dfrac{b}{t_f} \leq 6.4$

Compression flange of box section $\dfrac{b}{t_f} \leq 10$

Outstanding stiffener $\dfrac{b_s}{t_s} \leq 3.2$

Web in shear $\dfrac{b}{w} \leq 22$

where   b = flange width, in.

b$_s$ = stiffener width, in.

d = depth of section, in

t$_f$ = flange thickness, in.

t$_s$ = stiffener thickness, in.

w = web thickness, in.

The following limitations on the dimensions of ASTM A-7, A-36 or A-373 steel sections are taken from Ref. 7.04. The relations are based on an axial yield stress level of 33 ksi, but tests have shown that sections meeting these requirements perform satisfactorily under rapid loading in spite of the increased yield point.

Stability Requirement for A-7, A-36 and A-373 Steel Sections
(Notation as shown for Aluminum)

Compression flange of WF, I or H section	$\frac{b}{t_f} \leq 17$
Compression flange of box section	$\frac{b}{t_f} \leq 43$
Outstanding stiffener	$\frac{b_s}{t_s} \leq 8.5$
Web in shear	$\frac{d}{w} \leq 43$

Interaction expressions for more complex stress states are given in Ref. 7.04 which also contains more general expressions which must be used to set stability limitations on the dimensions of sections fabricated of higher strength steel.

The structural resistance is defined by the yield level and the ductility. The product of these quantities is a measure of the energy absorption capacity of the structure. Continuity of structural elements provides an increased energy absorption capacity and should be provided where practicable in metal blast resistant structures. To attain continuity, joints should be designed to develop the full flexural or axial capacity

of the member; otherwise, deformations will be concentrated at the joints
and the overall ductility of the element will be reduced.

Welded construction can readily provide structural continuity.
However, approved welding procedures, good weld and fabrication details,
properly selected welding rods, and weldable base metal are essential
if brittle response is to be avoided. Riveted or bolted joint details
should be free of sheared edges and punched holes, and adequate edge
distances should be provided.

3) Design in Reinforced Concrete. Reinforced concrete beams
and slabs have a resistance function similar to that shown in Fig. 7.02,
if brittle behavior is avoided, i.e., the member responds in flexure
instead of diagonal tension or shear. Since brittle response is undesirable,
reinforced concrete beams and slabs are proportioned to respond in flexure,
i.e., the resistance in flexure is deliberately made less than that in
diagonal tension or pure shear. Flexural response may itself be brittle
if failure occurs by crushing of the concrete before yielding of the
reinforcement. For this reason, the steel percentage must be held to such
a level that the member is under-reinforced.

Reinforced concrete flexural members are proportioned for moment
resistance by ultimate strength theory using the stresses for steel and
concrete given in Sec. 7.05 of this chapter. Shear and diagonal tension
resistances are computed based on the static material properties since it
is desired to avoid these modes of response.

Where possible, no more than 2 percent flexural steel should be
used. The net flexural steel, the difference between the percentages of
tensile and compressive steel, should be less than 1.5 percent. In unusual
circumstances, it is permissible to use as much as $40 \ f'_{dc}/f_{dy}$ percent
net flexural steel when compressive steel is provided. Doubly reinforced
members should be used whenever practicable since the ductility is improved,
rebound resistance is provided, and the placing of shear reinforcement is
facilitated. It is necessary to provide a minimum amount of tensile
reinforcement to avoid brittle behavior. Normally at least 0.25 percent
tensile steel should be provided, but in unusual circumstances the tensile
steel percentage may be reduced to $2 \ f'_{dc}/f_{dy}$.

If the addition of web reinforcement is required to prevent shear or diagonal tension failure, at least 0.25 percent should be used. Only vertical stirrups are to be used for diagonal tension reinforcement, since inclined stirrups provide a plane of weakness when the loading direction is reversed in rebound.

Under-reinforced flexural members proportioned to preclude response in shear or diagonal tension are designed for a ductility factor of 3. Compression members or over-reinforced flexural members should be designed for a ductility factor of 1.3.

Because structural continuity is required for proper behavior, reinforcing splices must be designed and fabricated with care. Reinforcing welds must develop the yield strength of the bar, and bar lap splices must satisfy the ACI requirements. In zones of high bar stress, the lap should exceed the ACI minimum; a minimum lap of 30 bar diameters is recommended. Care must also be taken to provide adequate anchorage for reinforcement. An anchorage should be capable of developing the yield strength of the bar, and all bars used should meet the ASTM A-305 specification for deformations.

4) _Design in Timber._ In general, timber lacks the strain capacity required to develop a fully plastic moment at a section. Therefore, designs in timber should be based on elastic theory working stress design, but the increased allowable stresses should be used. Timber strain hardens rapidly; therefore, the inelastic regions of the member will be of considerable extent. Thus, the ductility factor of 3 used for design charts in this report appears reasonable for timber flexural members. Timber tension members also may be designed for a ductility factor of 3, if the connections develop the full strength of the member. Timber columns should be proportioned for a ductility factor of 1.3.

7.05 STRUCTURAL PROPERTIES OF MATERIALS

1) _General._ In this section are presented the strength properties of materials considered suitable for entrance structures. In many instances the variety of commercially available materials is too great for complete description of pertinent properties in this report. Therefore, expressions for design stresses for protective design are given in lieu of extensive strength tabulations.

Protective structures are designed on the basis of a predicted failure load, failure being defined either by the limit of acceptable deformation or by the collapse of the structural element. Normally a ductile, large deformation, failure mode is desired in design since large amounts of energy are absorbed in inelastic deformation. By making use of the energy absorption capability the resistance required of the design is greatly reduced.

The design stresses given herein correspond generally to the probable yield stress of the material under the blast loading conditions. These design stresses represent probable yield stresses for the material, not guaranteed minimum values, since it is desired to estimate the actual yield load for the structural element rather than a lower limit to the yield load. It is emphasized that the factor of safety for protective construction is primarily contained in the design loading, not in the evaluation of the resistance of the structural elements.

2). Concrete. Research has demonstrated that concrete provides increased resistance at rapid loading rates. The following design stresses for protective construction, based on the standard 28 day cylinder strength, f'_c, are taken from Ref. 7.01:

Dynamic Compressive Strength	$f'_{dc} = 1.25 f'_c$
Dynamic Bond Stress (for ASTM A-305 deformed bars)	$u_d = 0.15 f'_c$
Pure Shear Stress	$v_{dy} = 0.20 f'_c$
Dynamic Tensile Strength	$f_{dt} = 7.5\sqrt{f'_{dc}}$

3) Reinforcing Steel. Structural and intermediate grade reinforcing bars are fabricated from steel developing increased yield resistance under rapid loading. The following design stresses include the effects of the rate of load application (Refs. 7.01 and 7.03):

Structural Grade	$f_{dy} = 42$ ksi
Intermediate Grade	$f_{dy} = 52$ ksi

Hard grade, rail steel, and alloy steel bars do not exhibit pronounced loading rate effects on yield level. However, designs using these reinforcing steel materials should be based upon the probable yield level and not the guaranteed minimum yield level. When test data is not available, the design stress may be taken as the smaller of 1.10 times the minimum specified static yield strength or 0.90 times the specified minimum static tensile strength.

All reinforcing steel should have deformations satisfying ASTM A-305.

4) <u>Structural Steel.</u> The following design stresses are based on the yield strengths for the loading rate range expected in protective construction (Refs. 7.01 and 7.03):

DESIGN STRESSES FOR STEEL

Steel	Axial Stress f_{dy}, ksi	Shearing Stress v_{dy}, ksi	Allowable Bearing Stress	
			Single Shear f_{by}, ksi	Double Shear f_{by}, ksi
Structural Carbon,[1] ASTM A-7, A-36, or A-373	42	25		
Corrugated Iron[2]	34	30		
Welds	42	29		
Rivets ASTM A-141	40	30	60	80
ASTM A-195	60	40	80	80
Bolts ASTM A-307	32	19	40	40
ASTM A-325	50	30	60	60

[1] For higher strength structural steels, use an axial design stress, f_{dy}, equal to the smaller of 1.10 times the specified minimum yield or 0.90 times the specified minimum ultimate strength. For design shearing stress, v_{dy}, use 0.60 f_{dy}.

[2] The value of f_{dy} has been selected to be used with a plastic modulus, Z, of 1.5 times the section modulus, S.

5) <u>Aluminum</u>. Aluminum alloys subjected to loading rates
expected in protective construction do not show appreciable increases
in yield level over that from static tests. However, yield and ultimate
strengths such as those given in Table 4 of Ref. 7.05 are guaranteed
minimum values. The average strength values run about 15 percent higher
than these minimum values. Average values are tabulated below.

DESIGN YIELD STRESS VALUES FOR ALUMINUM

Alloy	Axial and Flexural Stress	Shearing Stress	Bearing Stress	Elastic Modulus	Weight
	f_{dy}, ksi	v_{dy}, ksi	f_{by}, ksi	E, ksi	pcf
6061-T6	40	23	64	10,000	169

6) <u>Timber</u>. Too many varieties of timber are available to include
tabulations of design stresses in this report. Therefore, relationships
between protective design stresses and normal design stresses are given.
The normal design stresses for the various timber varieties and grades can
be found in most books on timber design, e.g., Refs. 7.06 and 7.07.

The resistance of wood is markedly influenced by the loading
duration. The normal design stresses can be increased by a factor of two
for protective construction because of loading rate effects alone. In
addition, since no safety factor should be included in evaluating the
resistance, another factor of two may be applied to the design stress as
increased by the loading rate factor. Thus, the timber design stress for
protective construction equals 4 times the comparable design stress for
normal conditions.

The timber design stresses of particular interest include the
flexural stress, f_f, and the horizontal shear stress, v_h. The stresses
f_f and v_h are termed "allowable unit stresses for normal loading conditions."
For protective construction, the following dynamic stresses are used:

Flexure $\qquad\qquad f_{df} = 4 f_f$

Horizontal shear $\qquad v_{dh} = 4 v_h$

7) __Earth__. Few data concerning the shear strength of soils under dynamic loadings are available at this time. However, the existing evidence indicates that it is conservative, but not excessively so, to use the strength obtained from conventional tests, e.g., the unconfined compression test and the standard penetration resistance test, in the design for dynamic loads. It should be noted that it is appropriate to use the undrained shearing resistance in all cases since drainage cannot occur during the short loading times.

The following rules for evaluating bearing resistance for blast loadings, adapted from Ref. 7.01, apply to footings bearing on horizontal surfaces of extensive soil masses.

Earth Material	Bearing Resistance
Rock	1.0 times the crushing strength in unconfined compression plus the side-on overpressure for sound rock. The presence of discontinuities and weathering will dictate the use of a smaller value.
Granular Soil	The bearing pressure for one inch settlement of the footing under static loads plus the side-on overpressure.
Cohesive Soil	Three-quarters of the failure load of the footing under static loads plus the side-on overpressure.

Where detailed soil information is not available, the bearing resistance for blast loadings is taken as twice the conventional or local building code allowable static pressure, plus the side-on overpressure.

The use of the above bearing resistances will result in footing displacements comparable in magnitude to those occurring under conventional structures subjected to normal design loading. However, in many cases it is desirable to make footings smaller so that the footings displace enough to give some reduction in the structural strength requirements.

An idealized resistance function for the footing, analogous to that
shown in Fig. 7.02 for a structural element, may be obtained in the
following manner.

For granular soils, estimate the ultimate bearing pressure, q_y,
and the bearing pressure for one inch settlement, q_1, for the particular
footing size in question. These may be estimated using methods described
in Ref. 7.08.

The settlement at q_y may be taken to be

$$x_y = 1 \text{ inch} \left[\frac{q_y}{q_1} \right]$$

For clay, estimate the ultimate bearing pressure, q_y, using
the unconfined compression strength, i.e., q_y equals approximately 3 times
the unconfined compressive strength. The corresponding settlement x_y
may be approximated by computing the vertical displacement at the surface
of an elastic body loaded by a distributed load. Convenient methods for
this calculation are given in Refs. 7.09 and 7.10. The modulus of
elasticity may be taken as the initial tangent modulus obtained from an
unconfined compression test, and a value of Poisson's ratio equal to 0.5
may be used.

The resistance functions for the footings thus obtained may be
used to determine the displacement of the footing for a given bearing
pressure-time function and the footing size can be adjusted to produce
larger or smaller displacements as required by the structure. This
procedure will give higher bearing pressures than those tabulated above
(Ref. 7.01).

7.06 RESISTANCE EXPRESSIONS

Tabulations of the equations involved in the evaluation of the resistance of structural elements of various materials are presented in the following tables. These expressions define the flexural resistance, shearing resistance, natural period in flexure, and yield deflection. The design stresses to be used with these expressions are found in Sec. 7.05. The design charts in Sec. 7.07 are based on these resistance expressions.

NOTATION FOR TABLE 7.01

$\alpha \quad = L_s/L_\ell$ (design as 1-way in short direction for $\alpha < \frac{1}{2}$)

$A \quad$ = total area of element, in^2

A/b = A per inch width, in.

$b \quad$ = width of element of section, in.

$d \quad$ = depth of structural element, in.

$E \quad$ = elastic Youngs modulus, psi

f_{dy} = dynamic tensile yield stress, psi

$I \quad$ = moment of inertia of element, in^4

I/b = I per inch width, in^3

$k_1 \quad = (77 + 180 \, \alpha^3) \, \dfrac{Et^3}{12L_s^4}$, psi/in

$k_2 \quad = (307 + 500 \, \alpha^3) \, \dfrac{Et^3}{12L_s^4}$, psi/in

$k_\alpha^2 = 3 - 2\alpha\sqrt{\alpha^2 + 3} + 2\,\alpha^2$

$L \quad$ = 1-way plate span, in.

$L_\ell \quad$ = 2-way long span, in.

$L_s \quad$ = 2-way short span, in.

$S \quad$ = section modulus of element, in^3

S/b = S per inch width, in^2

$t \quad$ = plate thickness, in.

$t_w \quad$ = total web thickness of element, in.

v_{dy} = dynamic shearing yield stress, psi

$W \quad$ = plate weight, psf

$Z \quad$ = plastic modulus of section, in^3

$Z \cong$ = 1.5 S for corrugated plate
$\quad\quad$ 1.15 S for I or WF section

Z/b = Z per inch width, in^2

TABLE 7.01

RESISTANCE EXPRESSIONS FOR METAL STRUCTURAL ELEMENTS

	Flexure q_y, psi	Shear q_y, psi	Period in Flexure T, sec.	Yield Defl. at c_a x_y in
FLAT PLATE SECTION				
1-way				
Simple Support	$2f_{dy}\left(\frac{t}{L}\right)^2$	$2v_{dy}\left(\frac{t}{L}\right)$	$9.4\times10^{-3}L^2\sqrt{\frac{W}{Et^3}}$	$\frac{5}{32}\frac{q_y L^4}{Et^3}$
Fixed Support	$4f_{dy}\left(\frac{t}{L}\right)^2$	$2v_{dy}\left(\frac{t}{L}\right)$	$4.1\times10^{-3}L^2\sqrt{\frac{W}{Et^3}}$	$\frac{q_y L^4}{25.6\, Et^3}$
2-way				
Simple Support	$6f_{dy}\left(\frac{t}{k_\alpha L_s}\right)^2$	$2v_{dy}\frac{t}{L_s}\left[\frac{2}{3}(1+\alpha)\right]$	$2.2\times10^{-2}\sqrt{\frac{W}{k_1}}$	$\frac{q_y}{k_1}$
Fixed Support	$12f_{dy}\left(\frac{t}{k_\alpha L_s}\right)^2$	$2v_{dy}\frac{t}{L_s}\left[\frac{2}{3}(1+\alpha)\right]$	$1.9\times10^{-2}\sqrt{\frac{W}{k_2}}$	$\frac{q_y}{k_2}$
CORRUGATED SECTION				
1-way				
Simple Support	$\frac{8f_{dy}}{L^2}\frac{Z}{b}$	$\frac{2v_{dy}}{L}\frac{A}{b}$	$2.7\times10^{-3}L^2\sqrt{\frac{W}{E}\frac{b}{I}}$	$\frac{5}{384}\frac{q_y L^4}{E}\frac{b}{I}$
Fixed Support	$\frac{16f_{dy}}{L^2}\frac{Z}{b}$	$\frac{2v_{dy}}{L}\frac{A}{b}$	$1.2\times10^{-3}L^2\sqrt{\frac{W}{E}\frac{b}{I}}$	$\frac{q_y L^4}{207\, E}\frac{b}{I}$
BUILT-UP SECTION				
1-way				
Simple Support	$\frac{8f_{dy}}{L^2}\frac{Z}{b}$	$2v_{dy}\frac{dt_w}{bL}$	$2.7\times10^{-3}L^2\sqrt{\frac{W}{E}\frac{b}{I}}$	$\frac{5}{384}\frac{q_y L^4}{E}\frac{b}{I}$
Fixed Support	$\frac{16f_{dy}}{L^2}\frac{Z}{b}$	$2v_{dy}\frac{dt_w}{bL}$	$1.2\times10^{-3}L^2\sqrt{\frac{W}{E}\frac{b}{I}}$	$\frac{q_y L^4}{307\, E}\frac{b}{I}$

NOTATION FOR TABLE 7.02

α $= L_s/L_\ell$ (design as 1-way in short direction if $\alpha < \frac{1}{2}$)

A_w = total web area of element, in^2

b = width of element of section, in.

d = depth of section, in.

E = elastic modulus, parallel to grain, psi

f_{df} = dynamic flexural design stress, psi

$H_\alpha = \alpha S_{p\ell} + \left[\dfrac{2 - \alpha}{3 - 2\alpha}\right] S_{ps}$ $= \dfrac{S_{ps}}{6_\alpha}$, in^2

I = moment of inertia of element, in^4

I_p = moment of inertia of plies with grain parallel to span per inch width, in^3

I_{pp} = moment of inertia of element considering only parallel plies, in^4

I_{ps} = I_p for short span, in^3

$J_\alpha = \dfrac{d/L}{1-2d/L}\left[\dfrac{2}{3}(1+\alpha)\right]$

$k_3 = \left[77 + 180\,\alpha^3\right]\dfrac{EI_{ps}}{L_s^4}$, psi/in

$k_\ell = \left[384 + 625\,\alpha^3\right]\dfrac{EI_{ps}}{L_s^4}$, psi/in

L = 1-way span, in.

L_ℓ = 2-way long span, in.

L_s = 2-way short span, in.

S = section modulus of element, in^3

S_p = effective section modulus per inch width, in^2
  = 0.85 times section modulus of plies parallel to span except $S_p =$
  1.50 times S of plies parallel to span for a 3-ply
  panel with face grain perpendicular to span

S_{pp} = section modulus of element considering only parallel plies, in^3

$S_{p\ell}$ = S_p for long span, in^2

S_{ps} = S_p for short span, in^2

v_{dh} = dynamic horizontal shear design stress, psi

W = weight of section, psf

TABLE 7.02

RESISTANCE EXPRESSIONS FOR WOOD STRUCTURAL ELEMENTS

	Flexure q_y, psi	Shear q_v, psi	Period in Flexure T, sec.	Yield Defl. at e, x_y, in
SOLID SECTION (Timber)				
1-way Simple Support	$\dfrac{8f_{df}}{L^2}\dfrac{S}{b}$	$\dfrac{4}{3}v_{dh}\dfrac{d/L}{1-2d/L}$	$9.4\times10^{-3}L^2\sqrt{\dfrac{W}{Ed^3}}$	$\dfrac{5}{32}\dfrac{q_yL^4}{Ed^3}$
Fixed Support	$\dfrac{12f_{df}}{L^2}\dfrac{S}{b}$	$\dfrac{4}{3}v_{dh}\dfrac{d/L}{1-2d/L}$	$3.7\times10^{-3}L^2\sqrt{\dfrac{W}{Ed^3}}$	$\dfrac{q_yL^4}{32Ed^3}$
BUILT-UP SECTION (Timber)				
1-way Simple Support	$\dfrac{8f_{df}}{L^2}\dfrac{S}{b}$	$\dfrac{2A_w}{bL}v_{dh}$	$2.7\times10^{-3}L^2\sqrt{\dfrac{W}{E}\dfrac{b}{I}}$	$\dfrac{5}{384}\dfrac{q_yL^4}{E}\dfrac{b}{I}$
Fixed Support	$\dfrac{12f_{df}}{L^2}\dfrac{S}{b}$	$\dfrac{2A_w}{bL}v_{dh}$	$9.5\times10^{-4}L^2\sqrt{\dfrac{W}{E}\dfrac{b}{I}}$	$\dfrac{q_yL^4}{384E}\dfrac{b}{I}$
PLATE SECTION (Plywood)				
1-way Simple Support	$\dfrac{8f_{df}}{L^2}S_p$	$\dfrac{8}{3}v_{dh}\dfrac{d/L}{1-2d/L}$	$2.7\times10^{-3}L^2\sqrt{\dfrac{W}{EI_p}}$	$\dfrac{5}{384}\dfrac{q_yL^4}{EI_p}$
Fixed Support	$\dfrac{12f_{df}}{L^2}S_p$	$\dfrac{8}{3}v_{dh}\dfrac{d/L}{1-2d/L}$	$9.5\times10^{-4}L^2\sqrt{\dfrac{W}{EI_p}}$	$\dfrac{q_yL^4}{384EI_p}$
2-way Simple Support	$\dfrac{12f_{df}}{L_s^2}M_\alpha$	$\dfrac{8}{3}v_{dh}J_\alpha$	$2.2\times10^{-2}\sqrt{\dfrac{W}{k_3}}$	$\dfrac{q_y}{k_3}$
Fixed Support	$\dfrac{24f_{df}}{L_s^2}M_\alpha$	$\dfrac{8}{3}v_{dh}J_\alpha$	$1.9\times10^{-2}\sqrt{\dfrac{W}{k_4}}$	$\dfrac{q_y}{k_4}$
BUILT-UP SECTION (Plywood)				
1-way Simple Support	$\dfrac{8f_{df}}{L^2}\dfrac{S_{pp}}{b}$	$\dfrac{4A_w}{bL}v_{dh}$	$2.7\times10^{-3}L^2\sqrt{\dfrac{W}{E}\dfrac{b}{I_{pp}}}$	$\dfrac{5q_yL^4}{384E}\dfrac{b}{I_{pp}}$
Fixed Support	$\dfrac{12f_{df}}{L^2}\dfrac{S_{pp}}{b}$	$\dfrac{4A_w}{bL}v_{dh}$	$9.5\times10^{-4}L^2\sqrt{\dfrac{W}{E}\dfrac{b}{I_{pp}}}$	$\dfrac{q_yL^4}{384E}\dfrac{b}{I_{pp}}$

NOTATION FOR TABLE 7.03

α = l_s/L_ℓ (design as 1-way in short direction if $\alpha < \frac{1}{2}$)

d = depth to centroid of tensile reinforcement, in.

E_c = elastic modulus of concrete, psi; $E_c \cong 1,000 \, f'_c$

E_s = elastic Youngs modulus of steel, psi

f'_c = standard 28-day compressive cylinder strength of concrete, psi

f_{dy} = dynamic tensile yield stress of reinforcement, psi

I = cracked section moment of inertia per inch width for short span, in^3

k' = depth factor for concrete stress block

$$= \sqrt{\frac{\phi n}{50} + \left(\frac{\phi n}{100}\right)^2} - \frac{\phi n}{100}$$

$$k_1 = \left[77 + 180 \, \alpha^3\right] \frac{E_c I_s}{L_s^4}, \text{ psi/in}$$

$$k_2 = \left[307 + 500 \, \alpha^3\right] \frac{E_c I_s}{L_s^4}, \text{ psi/in}$$

L = 1-way slab span, in.

L_ℓ = 2-way long slab span, in.

L_s = 2-way short slab span, in.

n = modular ratio E_s/E_c

ϕ' = percentage of tensile reinforcement at supports, 1-way slab

ϕ = percentage of tensile reinforcement at midspan, 1-way slab

$\phi_{\ell c}$ = percentage of tensile reinforcement in long direction at midspan

ϕ_{sc} = percentage of tensile reinforcement in short direction at midspan

$\phi_{\ell e}$ = percentage of tensile reinforcement in long direction at supports

ϕ_{se} = percentage of tensile reinforcement in short direction at supports

ϕ_v = percentage of web reinforcement

W = slab weight, psf

TABLE 7.03

RESISTANCE EXPRESSIONS FOR REINFORCED CONCRETE STRUCTURAL ELEMENTS

FLEXURE - q_y, psi

1-way Slab

Simple Supports $0.072 \; \phi \; f_{dy} (\frac{d}{L})^2$

Fixed Supports $0.072 \; (\phi' + \phi) f_{dy} (\frac{d}{L})^2$

2-way Slab

Simple Supports $0.108 \; \phi_{sc} f_{dy} \; (\frac{d}{L_s})^2 \left[\alpha \frac{\phi_{1c}}{\phi_{sc}} + \frac{2 - \alpha}{3 - 2\alpha} \right]$

Fixed Supports $0.108 \; (\phi_{sc} + \phi_{se}) \; f_{dy} (\frac{d}{L_s})^2 \left[\alpha \frac{\phi_{1c} + \phi_{1e}}{\phi_{sc} + \phi_{se}} + \frac{2 - \alpha}{3 - 2\alpha} \right]$

PURE SHEAR - q_y, psi

1-way Slab

Simple Supports $0.44 \; f'_c \; \frac{d/L}{1 - d/L}$ for $\frac{d}{L} \le 0.2$

                    $0.55 \; f'_c$ for $\frac{d}{L} \ge 0.2$

Fixed Supports   Same as for 1-way Slab, Simple Support

2-way Slab

Simple Supports $\frac{2}{3} (1 + \alpha)$ times value for a 1-way Slab spanning the short direction when $\alpha \ge \frac{1}{2}$

Fixed Supports   Same as for 2-way Slab, Simple Support

DIAGONAL TENSION - q_y, psi

1-way Slab

Simple Supports $33.3 \left[1 + \frac{2\phi_v}{10^5} f_{dy} \right] \sqrt{\phi f'_c} (\frac{d}{L})^2$ or

                 $3.5 \sqrt{f'_c} \cdot \frac{d}{L}$ } whichever is greater

Fixed Supports $100 \left[\frac{1}{3} + \frac{1}{2} \frac{\phi'}{\phi} \right] \left[1 + \frac{2\phi_v f_{dy}}{10^5} \right] \sqrt{\phi f'_c} (\frac{d}{L})^2$ or

                 $3.5 \sqrt{f'_c} \frac{d}{L}$ } whichever is greater

2-way Slab

Simple Supports   } $\frac{2}{3} (1 + \alpha)$ times appropriate value for a 1-way Slab
Fixed Supports   spanning the short direction $(\alpha \ge \frac{1}{2})$

TABLE 7.03 CONTINUED

PERIOD - T, sec	YIELD DEFL. at $\mathfrak{C}$ - x_y, in

1-way Slab

Simple Supports $\quad \dfrac{L^2}{42,500 \ d\sqrt{\bullet}}$ $\qquad \dfrac{5}{384} \dfrac{q_y L^4}{E_c I}$

Fixed Supports $\quad \dfrac{L^2}{85,000 \ d\sqrt{\bullet}}$ $\qquad \dfrac{q_y L^4}{307 \ E_c I}$

2-way Slab

Simple Supports $\quad 2.2 \times 10^{-2} \sqrt{\dfrac{W}{k_1}}$ $\qquad q_y/k_1$

Fixed Supports $\quad 1.9 \times 10^{-2} \sqrt{\dfrac{W}{k_2}}$ $\qquad q_y/k_2$

7.07 DESIGN CHARTS AND TABLES

This section contains charts and tables from which a trial design section for structural elements can be obtained. The charts are based on Eqn. 7.01, the resistance parameters of the previous section, and the design stresses and ductility factors appropriate for the particular material, Sec. 7.04 and 7.05. It must be emphasized that these charts are based primarily upon a flexural mode of failure and that the trial designs must always be reviewed in order to insure (1) that resistance in other modes of failure is always greater than that in flexure and (2) that the accompanying structural deformations will not be of such a magnitude that door operation becomes difficult or impossible.

The tables included give the appropriate flexural properties of standard structural sections and the corresponding weight of the section. They are to be used in conjunction with design charts to aid in the selection of a structural section with satisfactory resistance.

Charts 7.01 through 7.09 refer primarily to structural carbon steel elements with: a dynamic tensile yield stress in steel, f_{dy}, of 42,000 psi; a ductility factor, μ, of 10; a peak pressure, p_m, of 50, 100, and 200 psi; and a yield moment which is the fully plastic moment of the section. Charts 7.01 and 7.02 indicate the minimum thickness, t, of a flat steel plate for various 1-way span lengths with simple and fixed supports, while Charts 7.03 and 7.04 show the necessary steel plate thickness, t, for 2-way slab behavior. The required plastic modulus per unit width, Z/b, is given in Charts 7.05 and 7.06 for corrugated steel plate and in Charts 7.07 and 7.08 for built-up steel sections.

While all of the above results are based on a ductility factor of 10, results for other values of μ can be readily obtained by multiplying the t or Z/b obtained for $\mu = 10$, by the proper correction factor K_μ from Chart 7.09. It should be noted that μ values less than 10 make little difference in the results and, even for $\mu = 4$, the correction factor for thickness is less than 5% and for plastic moduli is less than 10%. Results for other values of dynamic tensile yield stress, f_{dy}, can be

obtained by multiplying the result obtained for $f_{dy} = 42,000$ psi by the

ratio $\sqrt{\dfrac{42,000}{f_{dy}}}$ in Charts 7.01 through 7.04 and by the ratio $\dfrac{42,000}{f_{dy}}$

in Charts 7.05 through 7.08.

Charts 7.10 through 7.14 refer to timber structural elements
with: peak pressures of 50, 100, and 200 psi; a ductility factor of 3;
and an elastic theory using increased allowable working stresses. The
charts can be used for any value of dynamic flexural design stress, f_{df},
but provide an immediate answer when f_{df} equals 4,000 psi.

The required depth of a solid timber section for various span
lengths is given in Chart 7.10 for a 1-way span on simple supports and
in Chart 7.11 for a 1-way span on fixed supports. In Chart 7.12 the depth-
flange thickness factor of built-up plywood sections required for various
span lengths is given for a 1-way span on simple and fixed supports.
For plywood plates on simple and fixed supports, the required effective
section modulus for various span lengths is shown in Chart 7.13 for a
1-way span and in Chart 7.14 for 2-way span conditions.

Charts 7.15 through 7.21 refer to reinforced concrete elements
with: a dynamic tensile yield stress of steel, f_{dy} of 44,000 psi for
structural grade steel and 52,000 psi for intermediate grade steel; a
ductility factor, μ, of 3; peak pressures, p_m, of 50, 100, and 200 psi;
and a flexural mode of failure. Chart 7.15 shows the required depth-
to-span ratio for various amounts of flexural reinforcement in 1-way
spans with simple and fixed supports. For other values of f_{dy}, multiply

the results for $f_{dy} = 44,000$ psi by the factor $\sqrt{\dfrac{44,000}{f_{dy}}}$.

Based on various values of the expression $\sqrt{f_c'}(\dfrac{d}{L})$, Chart 7.16

indicates the corresponding value of peak pressure, p_m, which would
result in a diagonal tension mode of failure and hence indicates whether
web reinforcement is required.

In Chart 7.17 for structural grade reinforcement, $f_{dy} = 44,000$
psi, and in Chart 7.18 for intermediate grade reinforcement, $f_{dy} = 52,000$

psi, is given the required percent of web reinforcement vs. $\sqrt{\dfrac{f'_c}{\varphi}}$ for

1-way slabs with simple supports $(\dfrac{\varphi'}{\varphi} = 0)$ and fixed supports to make the resistance of the structural element in diagonal tension equal or exceed the yield resistance of the same element in flexure.

For 2-way slab behavior the required depth-to-span ratio vs. flexural reinforcement for simple and fixed supports is given in Charts 7.19 and 7.20 for structural and intermediate grade steels, respectively. Results may be obtained for other values of f_{dy} by multiplying the value

obtained from the chart by the ratio of the $\sqrt{\dfrac{44,000}{f_{dy}}}$. The required

web reinforcement, φ_v, for 2-way spans, simple and fixed supports, is obtained by using the factors from Chart 21 according to the expression (AB minus C) where C is inversely proportional to f_{dy}.

Table 7.04 is used in conjunction with Charts 7.05 and 7.06. Tables 7.05, 7.06, 7.07 and 7.08 are used with Charts 7.07 and 7.08.

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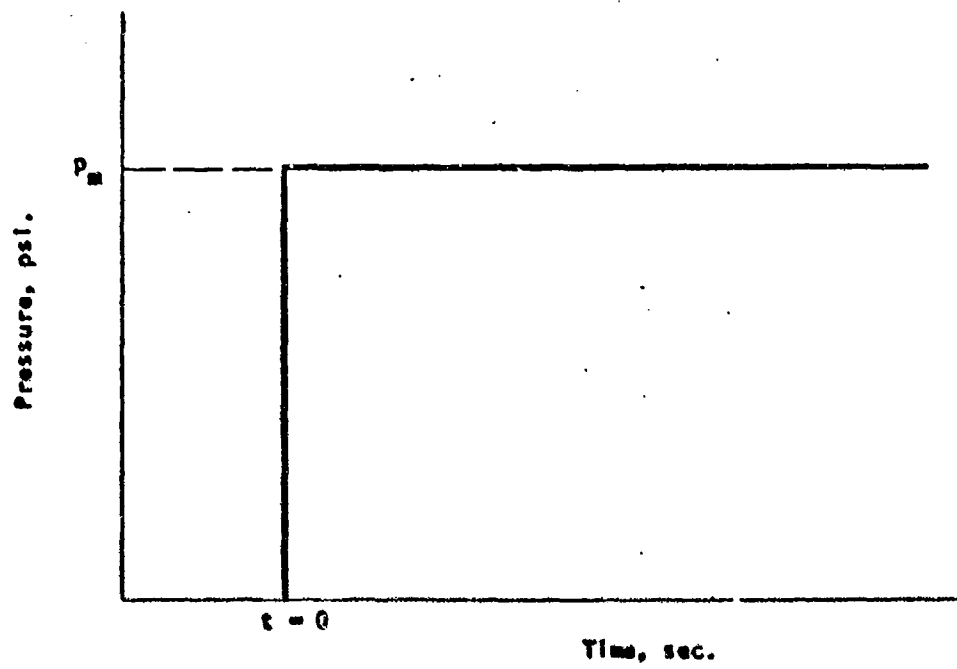
FIG. 7.01 DESIGN LOADING
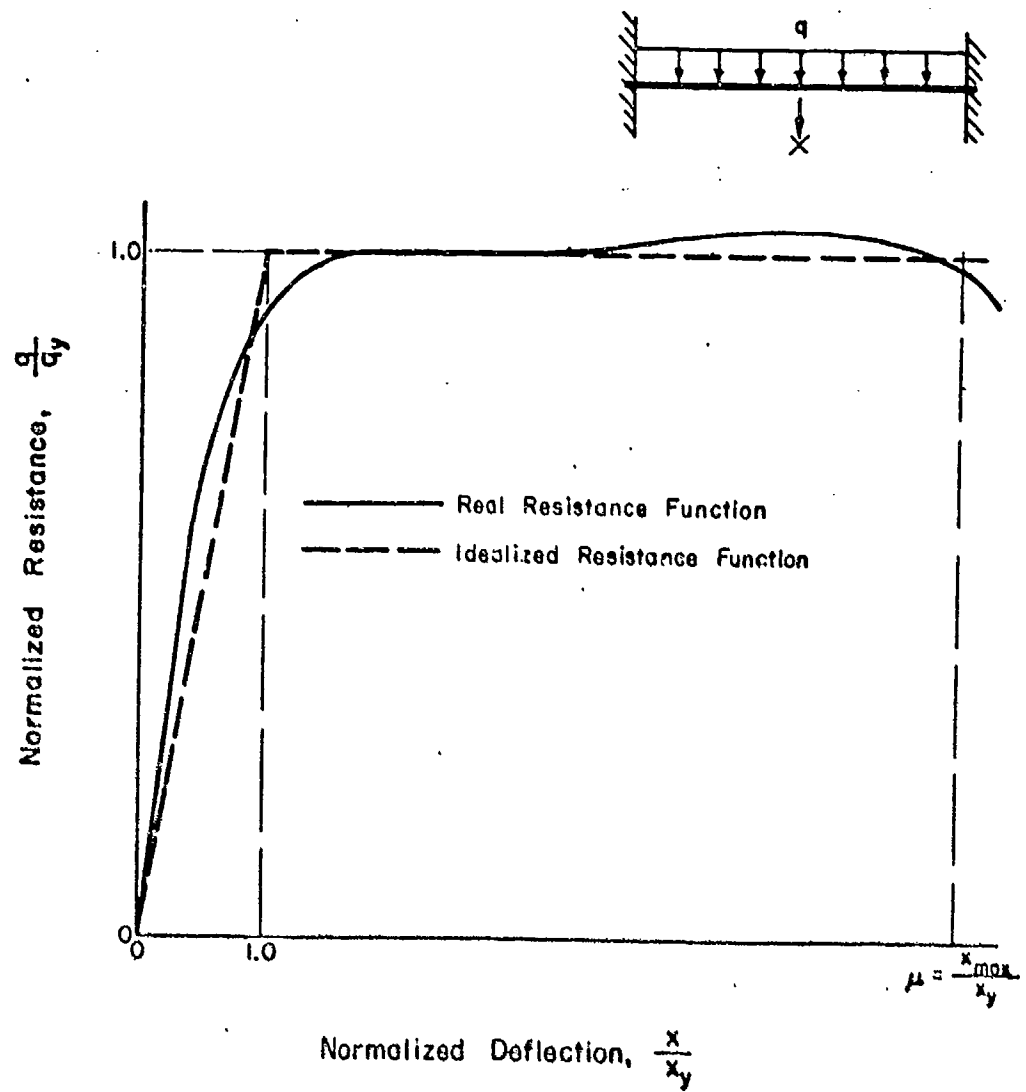
FIG. 7.02 TYPICAL REAL AND IDEALIZED LOAD - DEFLECTION CURVES
FOR A STRUCTURAL ELEMENT

FOR FLEXURE

$$p_m = 1.90 \, f_{dy} \left(\frac{t}{L}\right)^2, \text{ psi.}$$

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.
t = Plate Thickness, in.
L = Plate Span, in.
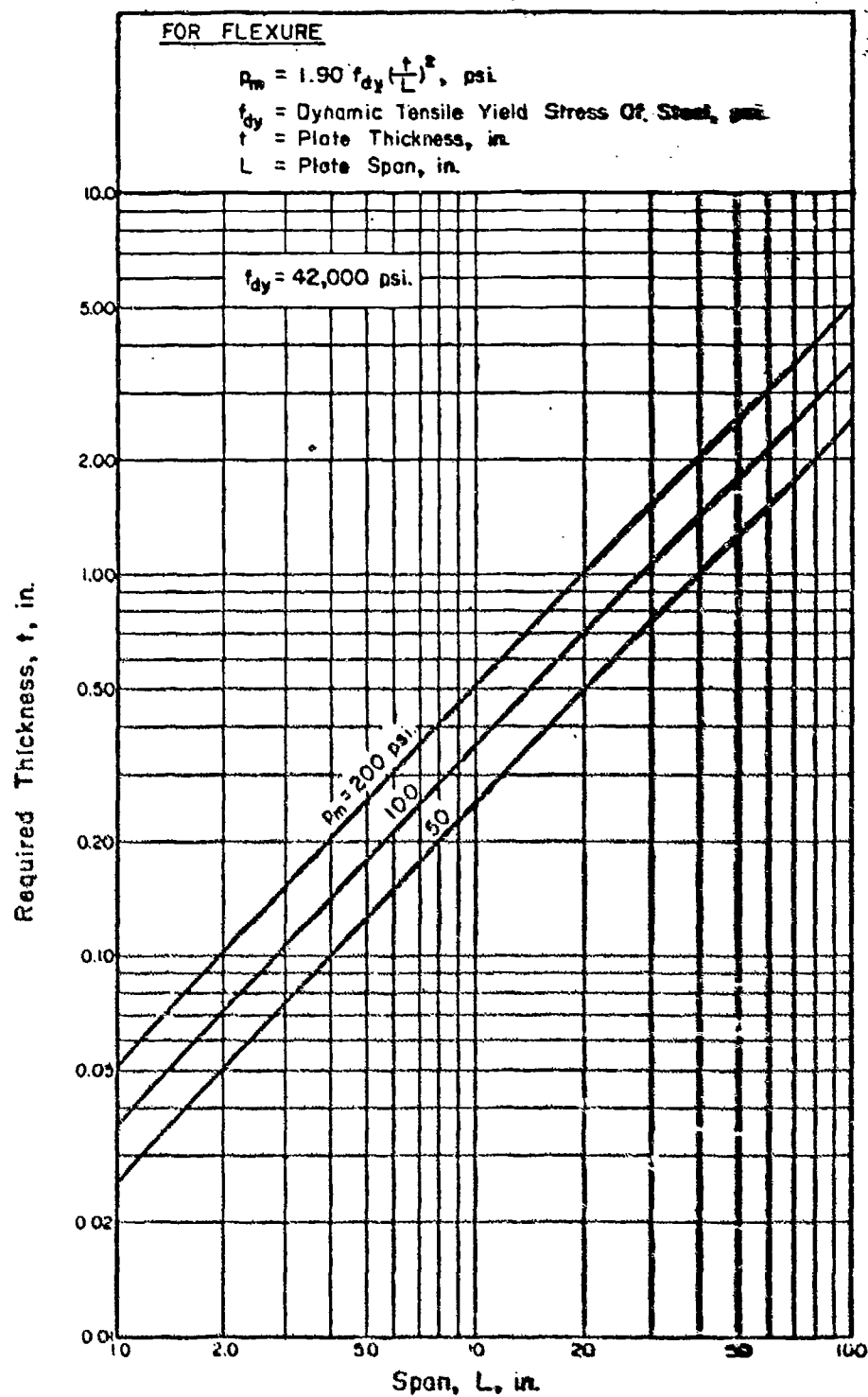
CHART 7.01 REQUIRED THICKNESS OF FLAT STEEL PLATES,

ONE-WAY SPAN, SIMPLE SUPPORTS, $\mu = 10$

172

FOR FLEXURE

$$p_m = 3.80 \ f_{dy} \left(\frac{t}{L}\right)^2, \ psi.$$

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.
t = Plate Thickness, in.
L = Plate Span, in.

f_{dy}= 42,000 psi.

P_m = 200 psi.
100
50

Required Thickness, t, in.

Span, L, in.
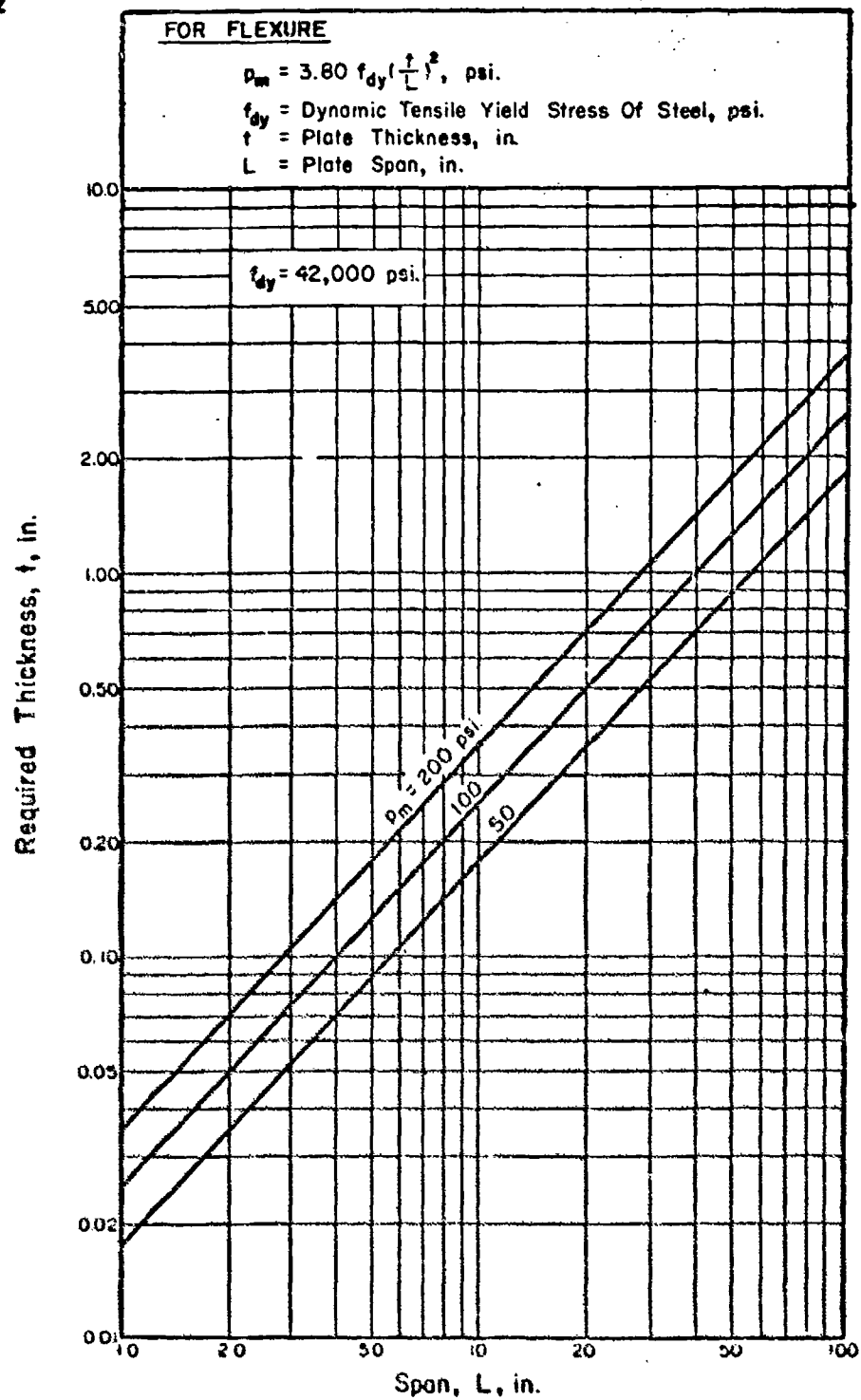
CHART 7.02 REQUIRED THICKNESS OF FLAT STEEL PLATES.

ONE-WAY SPAN, FIXED SUPPORTS, μ = 10
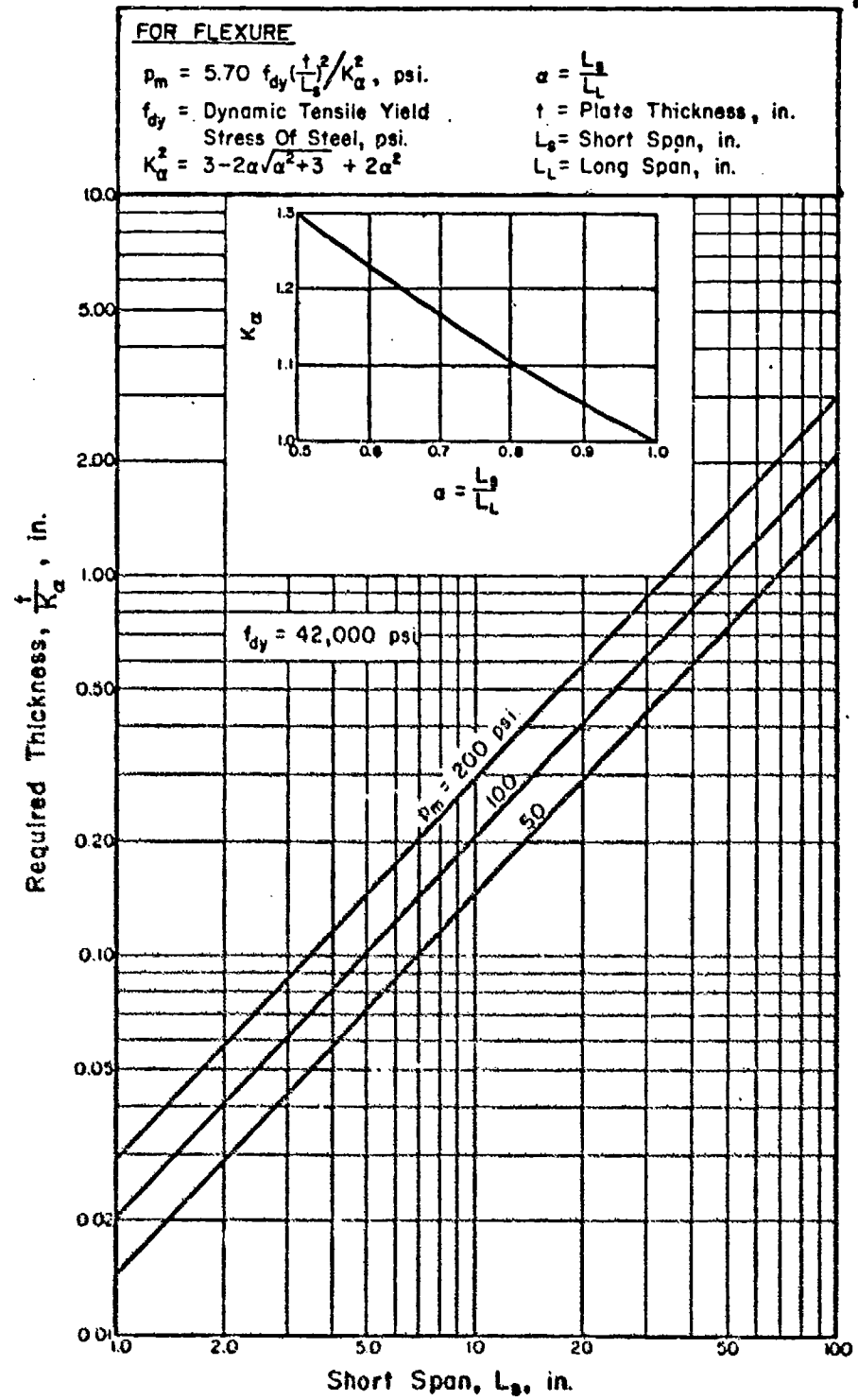
CHART 7.03 REQUIRED THICKNESS FOR FLAT STEEL PLATES,

TWO-WAY SPAN, SIMPLE SUPPORTS, μ = 10

FOR FLEXURE

$p_m = 11.40 \ f_{dy} (\frac{t}{L_s})^2 / K_a^2$, psi.

f_{dy} = Dynamic Tensile Yield
Stress Of Steel, psi.

$K_a^2 = 3 - 2a\sqrt{a^2 + 3} + 2a^2$

L_s = Short Span, in.
L_L = Long Span, in.
t = Plate Thickness, in.
Note: Check Designs For Shear
When p_m = 100 or 200 psi.

f_{dy} = 42,000 psi.

p_m = 200 psi.

100

50

Required Thickness, $\frac{t}{K_a}$, in.

Short Span, L_s, in.

K_a

$a = \frac{L_s}{L_L}$
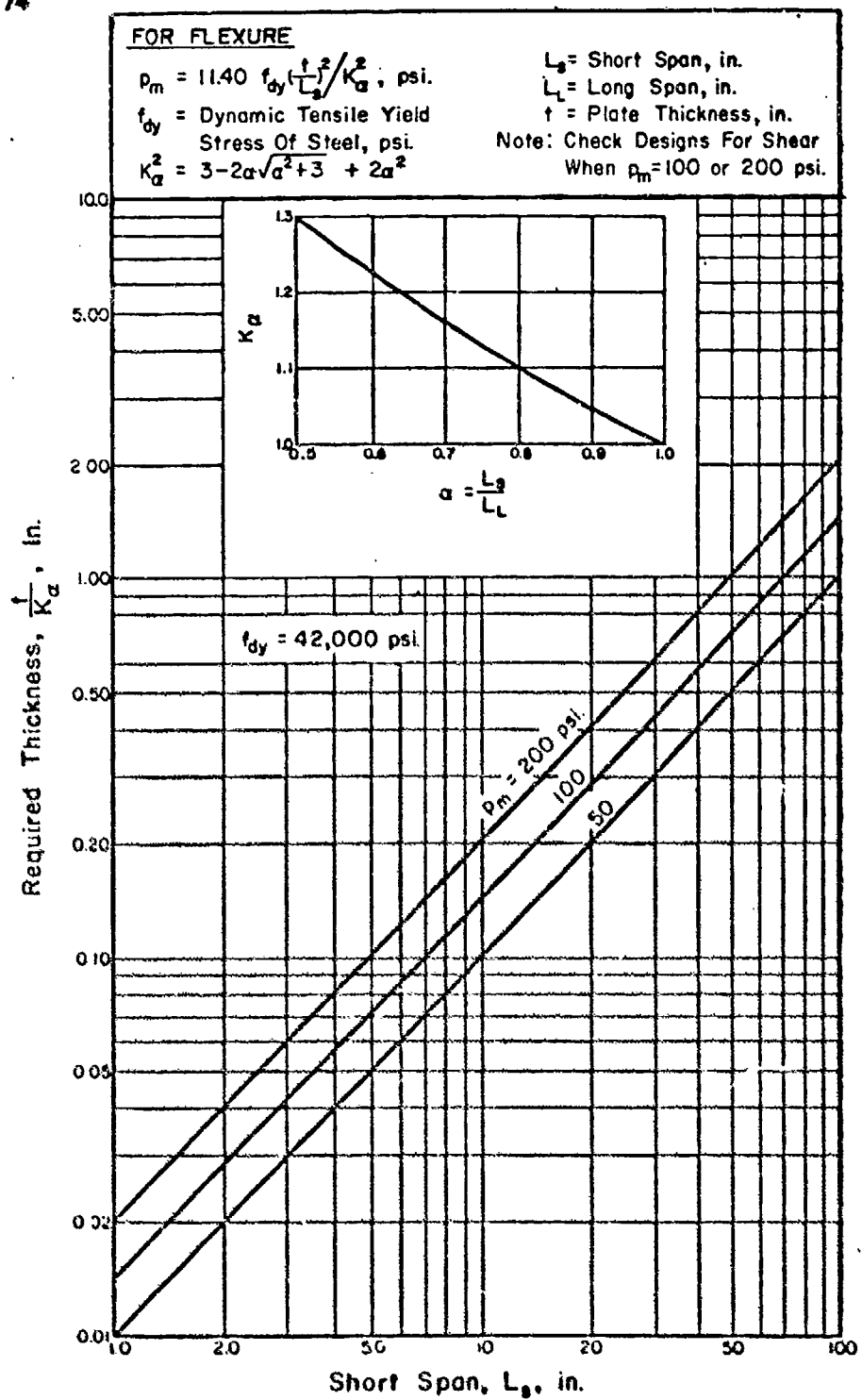
CHART 7.04   REQUIRED THICKNESS FOR FLAT STEEL PLATES,

TWO-WAY SPAN, FIXED SUPPORTS, μ = 10

FOR FLEXURE

$$p_m = 7.60\left(\frac{f_{dy}}{L^2}\right)\left(\frac{Z}{b}\right), \text{ psi.}$$

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.

L = Span, in.

$\frac{Z}{b}$ = Plastic Modulus Per Inch Width, in.²

f_{dy} = 34,000 psi.

(vertical left axis) Required Plastic Modulus Per Unit Width, $\frac{Z}{b}$, in.²

(vertical right axis) Required Multiplate (2 x6 Corrugations) Gage

(horizontal axis) Span, L, in.

$p_m = 200$ psi.

100

50
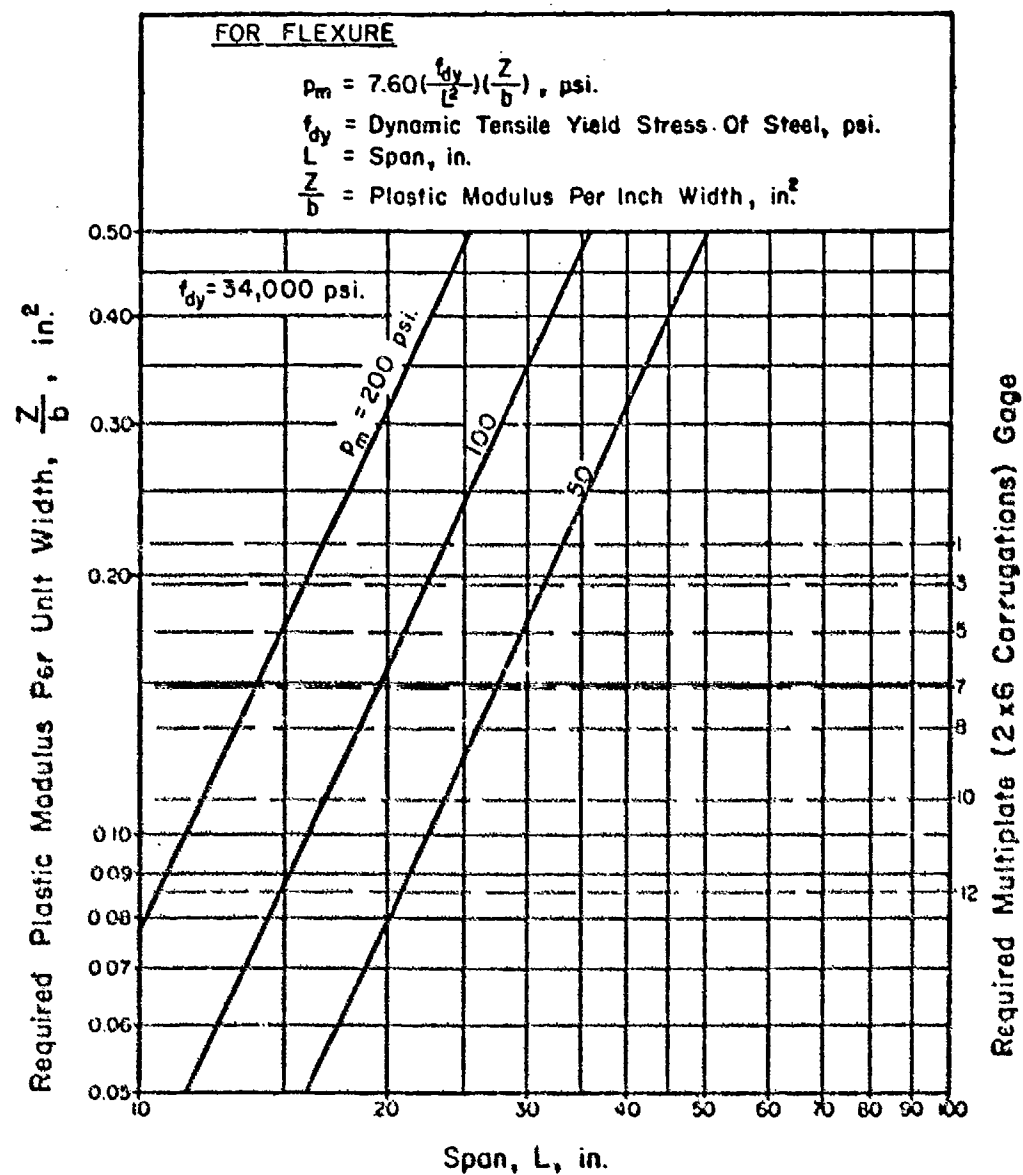
CHART 7.05 REQUIRED SECTION OF CORRUGATED STEEL PLATES,

ONE-WAY SPAN, SIMPLE SUPPORTS, μ = 10

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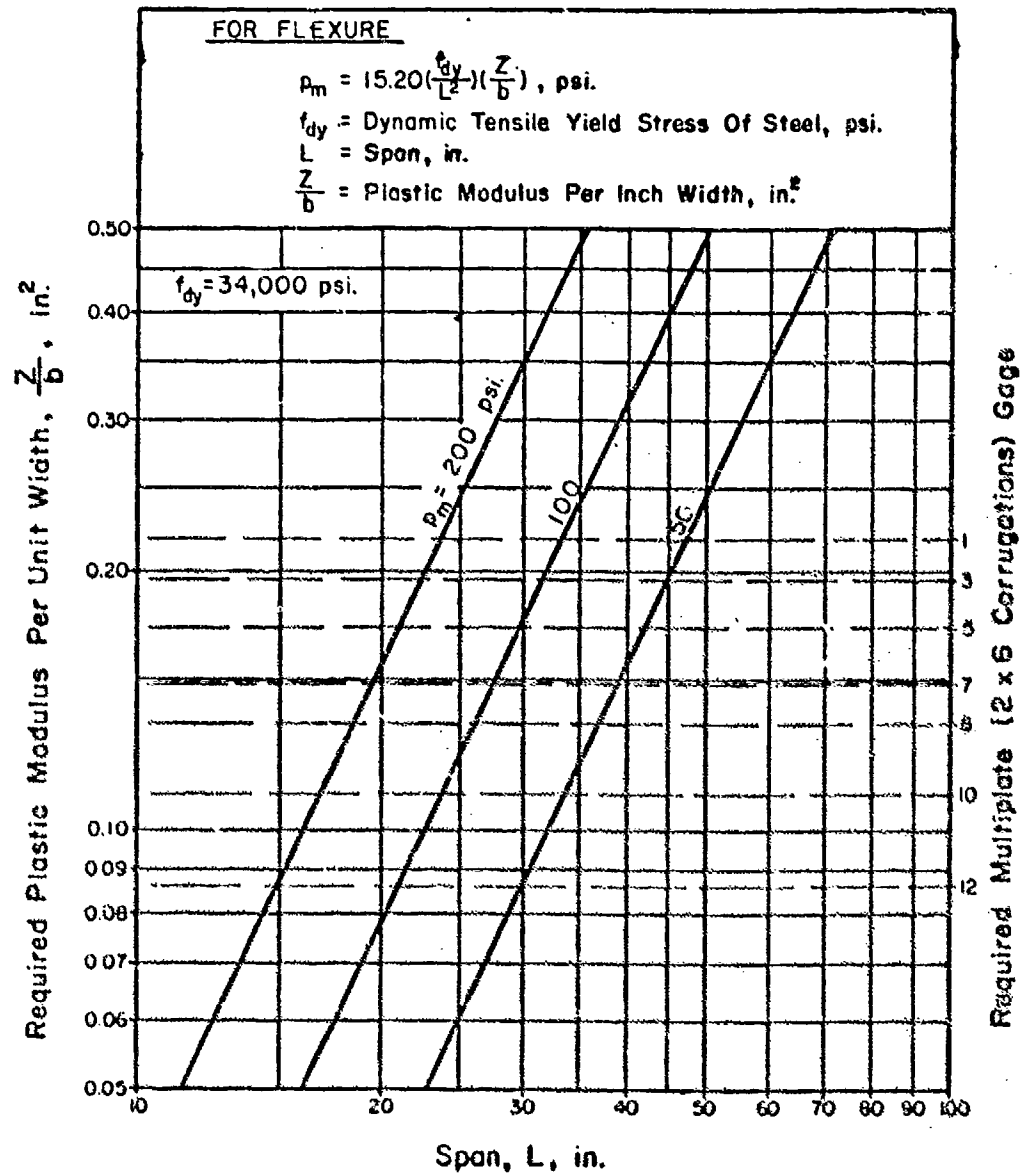
CHART 7.06   REQUIRED SECTION OF CORRUGATED STEEL PLATES,

ONE-WAY SPAN, FIXED SUPPORTS, μ = 10

FOR FLEXURE

For Simple Supports: $\rho_m = 7.60 \left(\frac{f_{dy}}{L^2}\right)\left(\frac{Z}{b}\right)$, psi.

For Fixed Supports: $p_m = 15.20 \left(\frac{f_{dy}}{L^2}\right)\left(\frac{Z}{b}\right)$, psi.

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.

Span, L, in.

Required Plastic Modulus Per Unit Width, $\frac{Z}{b}$, in²

f_{dy} = 42,000 psi.

p_m = 200 psi 100 50
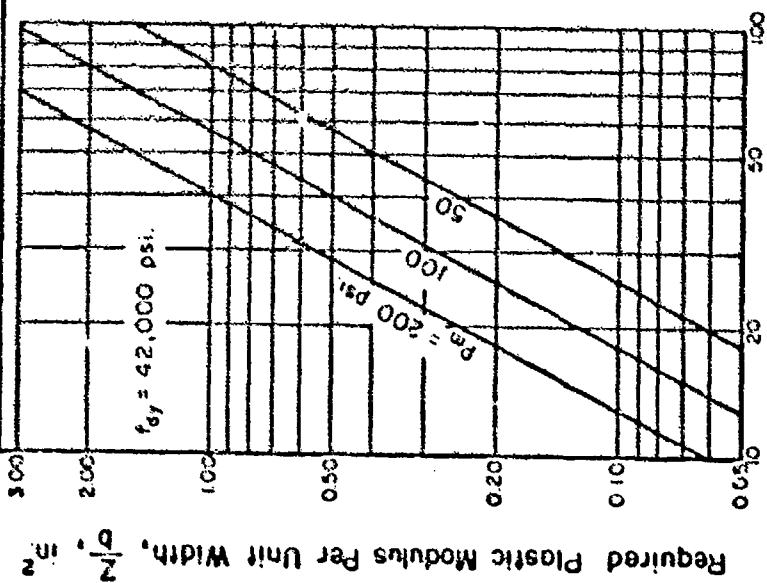
CHART 7.07 REQUIRED SECTION FOR BUILT-UP STEEL SECTIONS, ONE-WAY SPAN, SIMPLE SUPPORTS, μ = 10
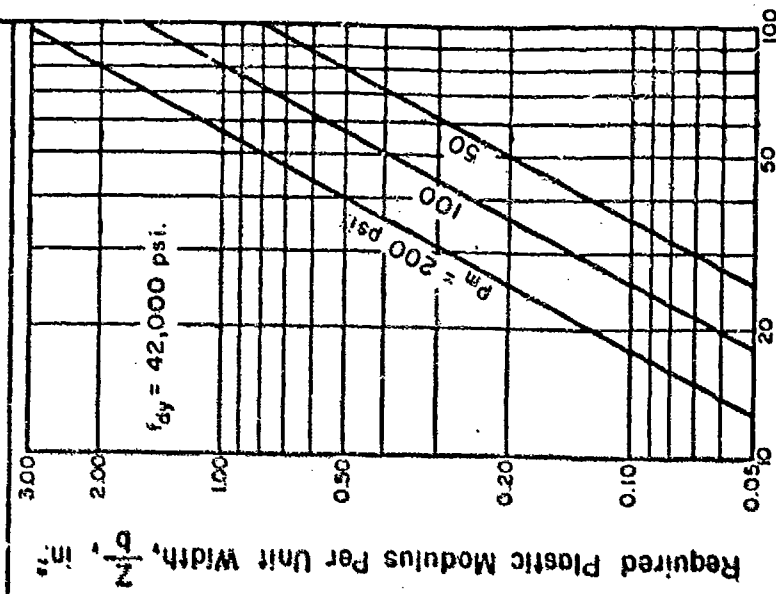
CHART 7.08 REQUIRED SECTION FOR BUILT-UP STEEL SECTIONS, ONE-WAY SPAN, FIXED SUPPORTS, μ = 10

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For Plate Thickness — $K_\mu = \sqrt{\dfrac{0.95}{1-\dfrac{1}{2\mu}}}$

For Plastic Modulus — $K_\mu = \dfrac{0.95}{1-\dfrac{1}{2\mu}}$

Plates — $t\big|_\mu = t\big|_{\mu=10}\, K_\mu$

Sections — $\dfrac{Z}{b}\big|_\mu = \dfrac{Z}{b}\big|_{\mu=10}\, K_\mu$
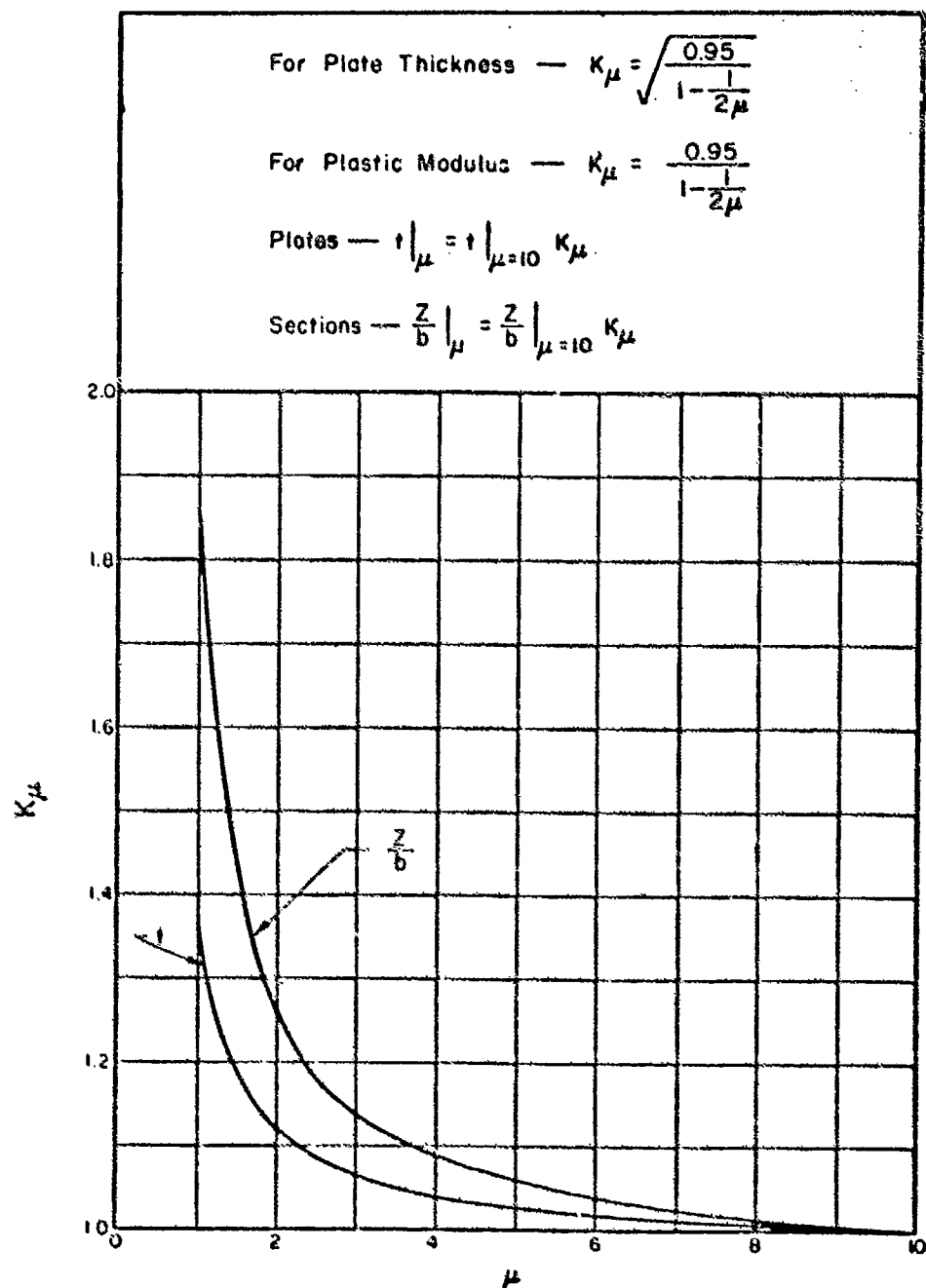
CHART 7.09   STEEL ELEMENTS, CORRECTION FACTOR FOR μ NOT

EQUAL TO 10

FOR FLEXURE

For Simple Supports: $p_m = 6.67 \left(\frac{f_{df}}{L^2}\right)(1-\frac{S}{b})$, psi.

For Fixed Supports: $p_m = 10.00 \left(\frac{f_{df}}{L^2}\right)(\frac{S}{b})$, psi.

f_{df} = Dynamic Flexural Design Stress, psi.

$\frac{S}{b} = \frac{d^2}{6}$ = Section Modulus Per Inch Width, in.²

FOR SHEAR

For Simple Supports: $\frac{d}{L} \leq \frac{1}{4}\left[1 - \sqrt{1 - 8\frac{V_d h}{f_{df}}}\right]$

For Fixed Supports: $\frac{d}{L} \leq \frac{1}{4}\left[1 - \sqrt{1 - \frac{16}{3}\frac{V_d h}{f_{df}}}\right]$

$K_1 = \sqrt{\frac{4000}{f_{df}}}$

CHART 7.11   REQUIRED DEPTH FOR SOLID TIMBER
SECTIONS, ONE-WAY SPAN, FIXED SUPPORTS, $\mu = 3$
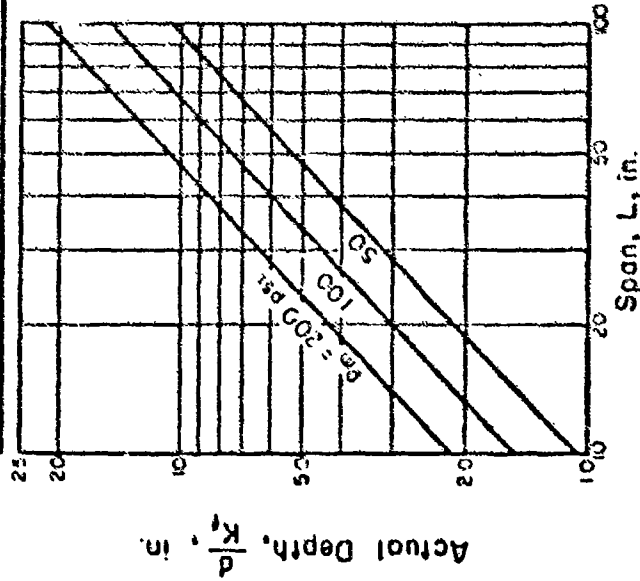
CHART 7.10   REQUIRED DEPTH FOR SOLID TIMBER
SECTIONS, ONE-WAY SPAN, SIMPLE SUPPORTS, $\mu = 3$

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FOR FLEXURE	FOR FLEXURE
For Simple Supports,	For Fixed Supports,
$p_m = \dfrac{6.67\, f_{df}}{L^2} \cdot \dfrac{S_{pp}}{b}$, psi.	$p_m = \dfrac{10.0\, f_{df}}{L^2} \cdot \dfrac{S_{pp}}{b}$, psi.

f_{df} = Dynamic Flexural Design Stress, psi.
S_{pp} = Effective Section Modulus (Parallel Plies Only), in.^{3}
b = Element Section Width, in.
t_f = Flange Thickness, in.
d = Depth, in.

$$K_g = \frac{4000}{f_{df}}$$
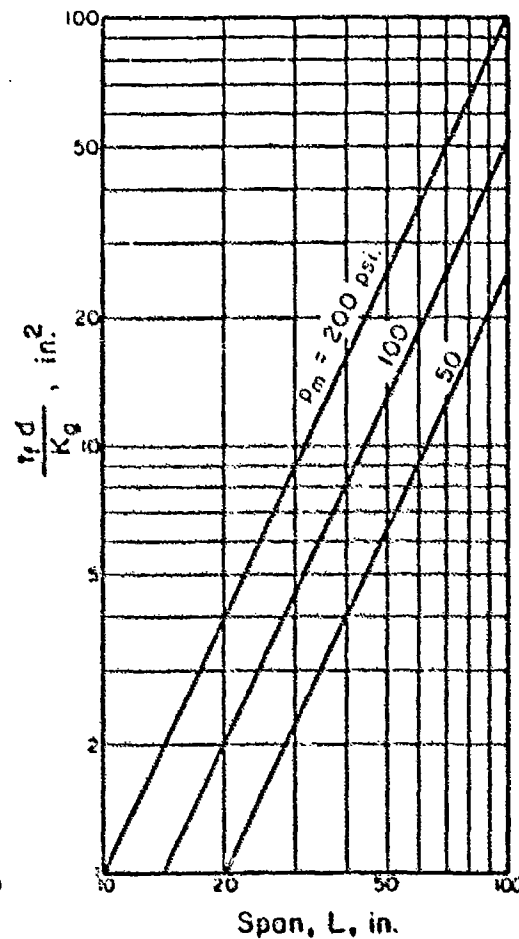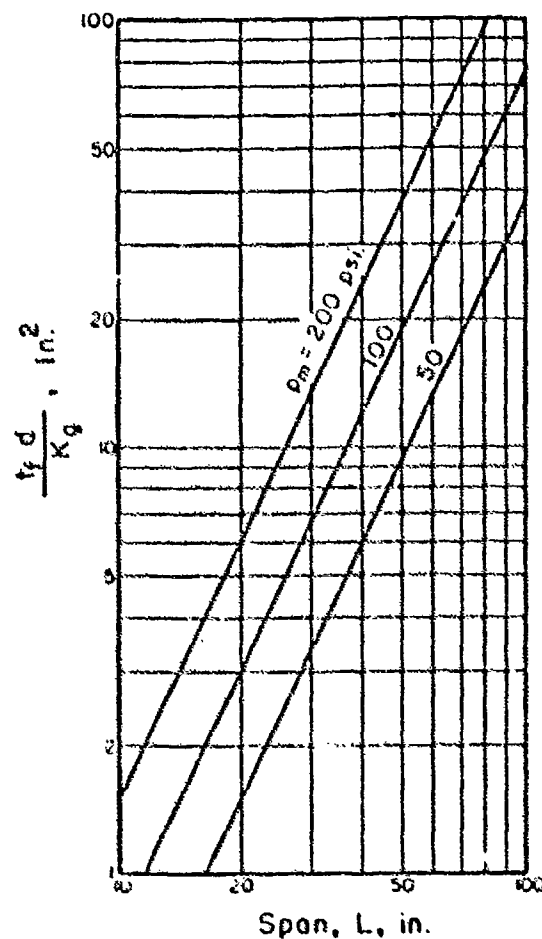
CHART 7.12 TRIAL DEPTH-FLANGE THICKNESS OF BUILT-UP PLYWOOD SECTIONS

VERSUS SPAN LENGTH FOR ONE-WAY SPAN, $\mu = 3$

FOR FLEXURE	FOR FLEXURE
For Simple Supports,	For Fixed Supports,
$p_m = \dfrac{6.67\, f_{df}}{L^2}\, S_p$, psi.	$p_m = \dfrac{10.0\, f_{df}}{L^2}\, S_p$, psi.

f_{df} = Dynamic Flexural Design Stress, psi.
S_p = Effective Section Modulus Per Inch Width, in.^{2}.

$$K_g = \frac{4000}{f_{df}}$$
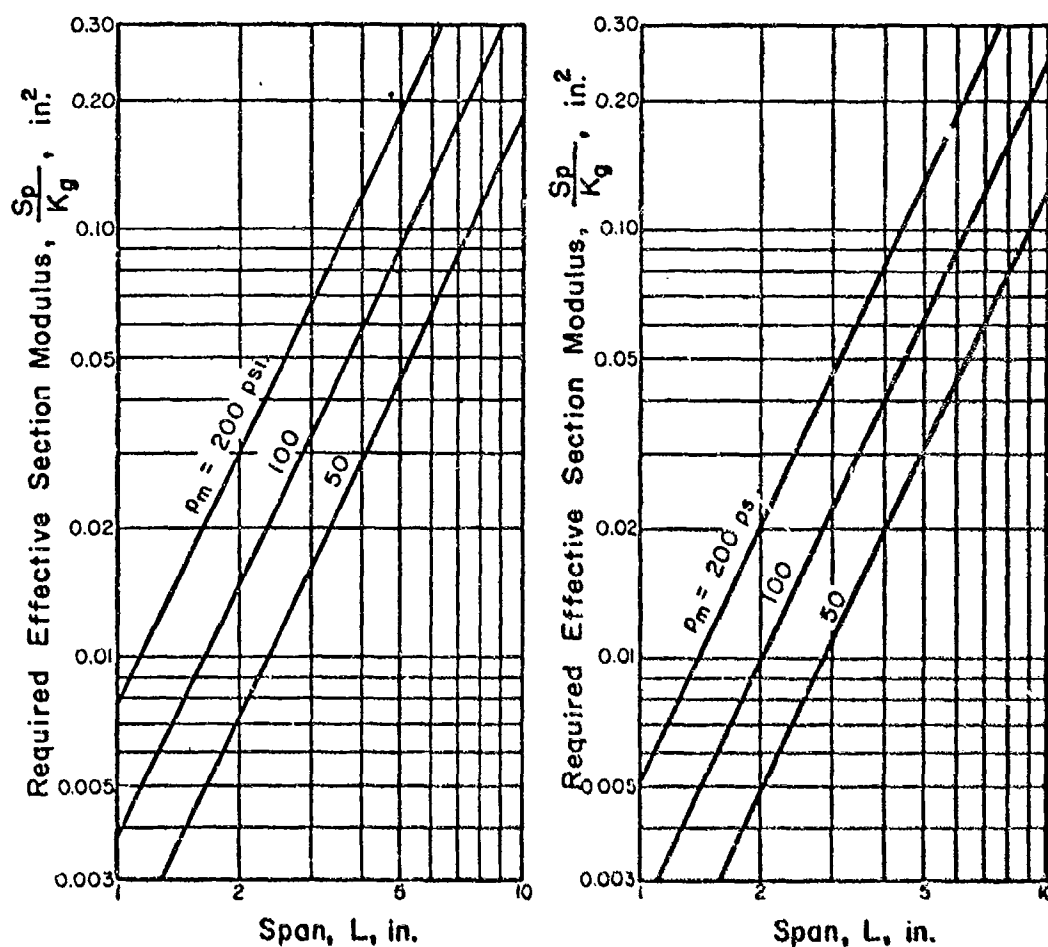
CHART 7.13 REQUIRED EFFECTIVE SECTION MODULUS OF PLYWOOD PLATES
VERSUS SPAN LENGTH FOR ONE-WAY SPAN, SIMPLE SUPPORTS AND FIXED SUPPORTS.

$\mu = 3$

FOR FLEXURE

For Simple Supports: $p_m = \dfrac{10 f_{df}}{L_s^2}\left(\dfrac{S_{ps}}{G_a}\right)$, psi.

and, $K_b = \dfrac{4000}{f_{df}}$

FOR FLEXURE

For Fixed Supports: $p_m = \dfrac{20 f_{df}}{L_s^2}\left(\dfrac{S_{ps}}{G_a}\right)$, psi.

and, $K_h = \dfrac{2000}{f_{df}}$

f_{df} = Dynamic Flexural Design Stress, psi.

S_{ps} = Effective Section Modulus Per Inch Width, Short Span, in.²

S_{pl} = Effective Section Modulus Per Inch Width, Long Span, in.²

$\dfrac{1}{G_a} = a\dfrac{S_{pl}}{S_{ps}} + \left(\dfrac{2-n}{3-2a}\right)$

L_s = Short Span, in.

L_L = Long Span, in.

Span, L_s, in.

Required Section Modulus, $\dfrac{S_{ps}}{K_b G_a}$, in.²

$p_m = 200$ psi

50 100

$a = \dfrac{L_s}{L_L}$

$\dfrac{S_{pl}}{S_{ps}} = 0.1$ 0.5   1.0   3.0   5.0   10

G_a

CHART 7.14   REQUIRED EFFECTIVE SECTION MODULUS OF PLYWOOD PLATES VERSUS SPAN LENGTH FOR TWO-WAY SPAN, SIMPLE SUPPORTS AND FIXED SUPPORTS, μ = 3

FOR FLEXURE

$p_m = 0.060(\phi + \phi')\, f_{dy}(\frac{d}{L})^2$, psi.

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.
ϕ = Percent Tensile Steel At Midspan.
ϕ' = Percent Tensile Steel At Supports.
d = Depth, in.
L = Span, in.

Note: For Simple Supports Use $\phi' = 0$ And $\phi \leq 2.0$ To Enter Charts.

Structural Grade Steel
f_{dy} = 44,000 psi.

$p_m = 200$ psi.
100
50

Intermediate Grade Steel
f_{dy} = 52,000 psi.

$p_m = 200$ psi.
100
50
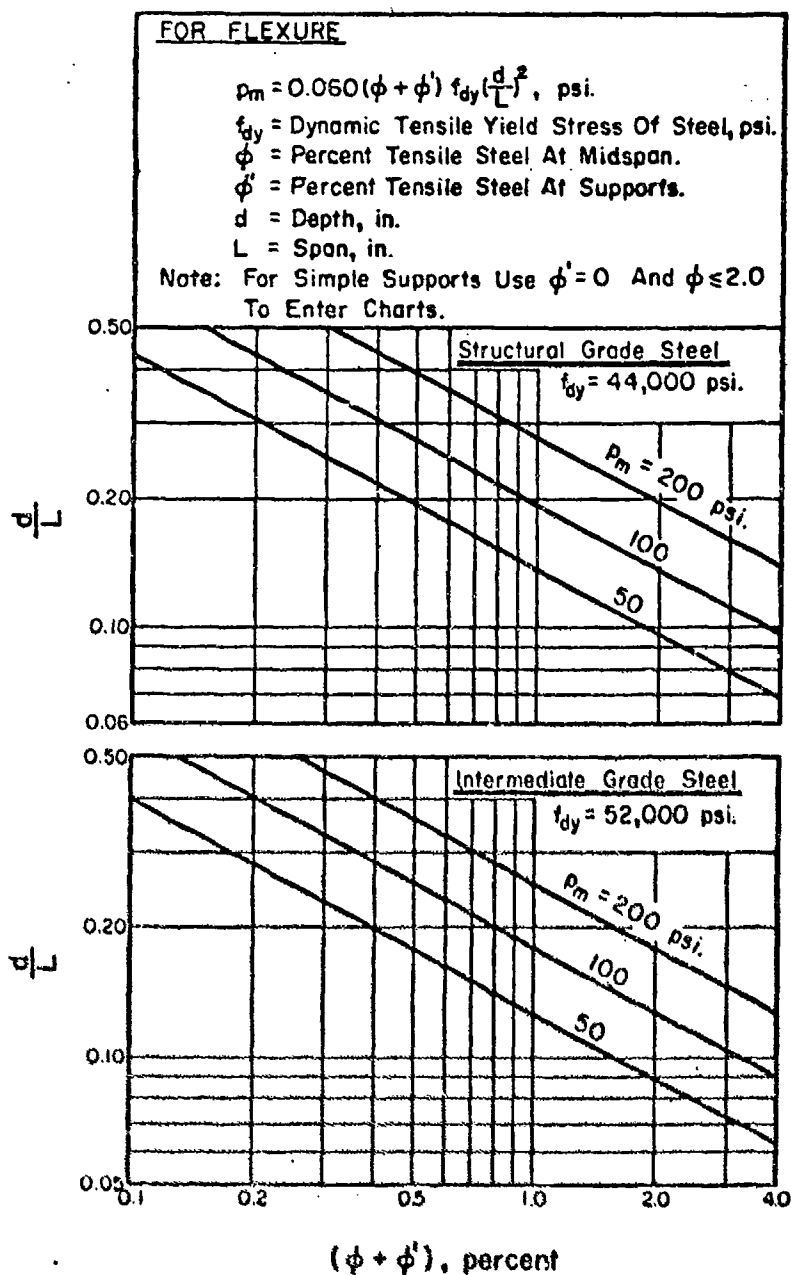
$(\phi + \phi')$, percent

CHART 7.15   REQUIRED FLEXURAL REINFORCEMENT AND DEPTH FOR
ONE-WAY SIMPLE OR FIXED SUPPORT REINFORCED CONCRETE SLABS, $\mu = 3$

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FOR DIAGONAL TENSION

$$p_m \geq 2.9 \sqrt{f_c'} \left(\frac{d}{L}\right), \text{ psi.}$$

f_c' = 28 Day Cylinder Strength, psi.
d = Depth, in.
L = Span, in.

Note: If p_m Given Here Is Greater Than p_m For
Flexure No Web Reinforcement Is Required.
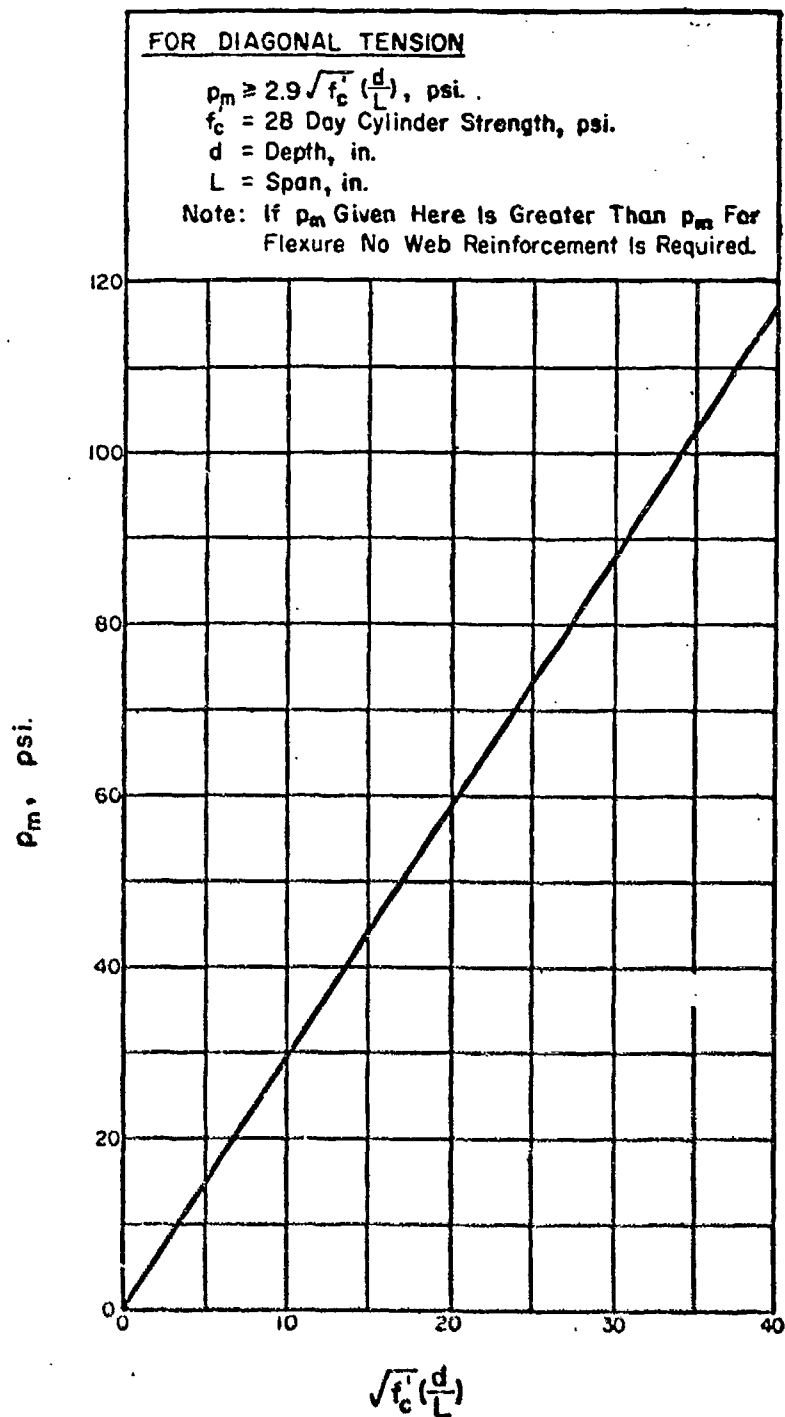
CHART 7.16 WEB REINFORCEMENT CRITERION FOR ONE-WAY REINFORCED

CONCRETE SLABS FOR $\mu = 3$

FOR DIAGONAL TENSION, $q_y \geq$ FLEXURE, q_y

$$100\left[\frac{1}{3}+\frac{1}{2}\frac{\phi'}{\phi}\right]\left[1+\frac{2\phi_v f_{dy}}{10^5}\right]\sqrt{f_c'\phi}\,(\frac{d}{L})^2 \geq 0.072\,(\phi+\phi')\,f_{dy}\,(\frac{d}{L})^2$$

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.
f_c' = 28 Day Cylinder Strength, psi.
ϕ = Percent Tensile Steel At Midspan.
ϕ' = Percent Tensile Steel At Supports.
d = Depth, in.
L = Span, in.

f_{dy} = 44,000 psi.
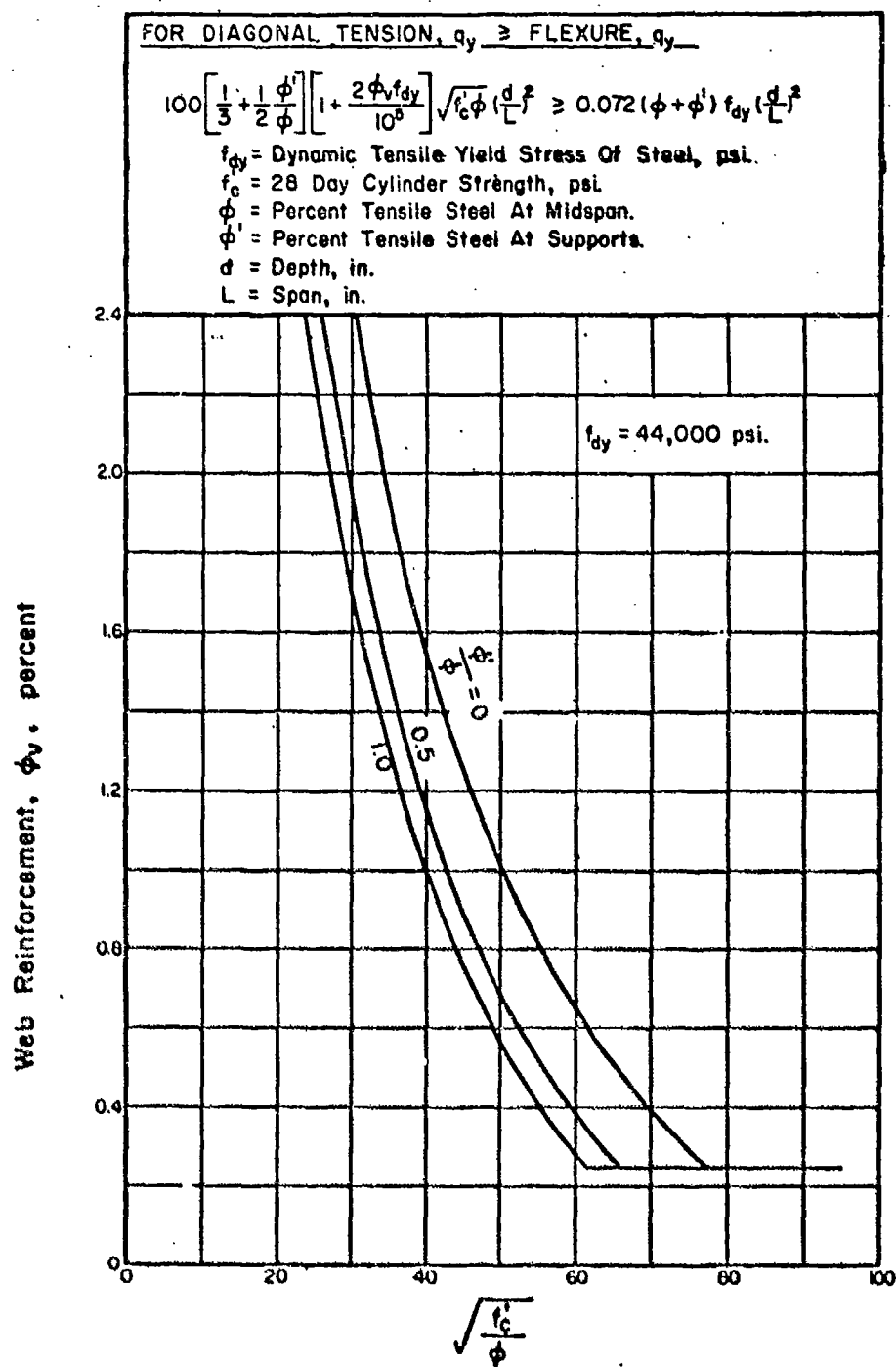
CHART 7.17   REQUIRED PERCENTAGE OF WEB REINFORCEMENT ONE-WAY REINFORCED
CONCRETE SLABS, SIMPLE OR FIXED SUPPORTS, STRUCTURAL GRADE REINFORCEMENT

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FOR DIAGONAL TENSION, $q_y \geqslant$ FLEXURE, q_y

$$100\left[\frac{1}{3}+\frac{1}{2}\frac{\phi'}{\phi}\right]\left[1+\frac{2\phi_v f_{dy}}{10^5}\right]\sqrt{f'_c\phi}\ (\frac{d}{L})^2 \geqslant 0.072\ (\phi+\phi')\ f_{dy}\ (\frac{d}{L})^2$$

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.
f'_c = 28 Day Cylinder Strength, psi.
ϕ = Percent Tensile Steel At Midspan.
ϕ' = Percent Tensile Steel At Supports.
d = Depth, in.
L = Span, in.

f_{dy} = 52,000 psi.

ϕ'/ϕ = 0

0.5

1.0

Web Reinforcement, ϕ_v, percent

$\sqrt{\dfrac{f'_c}{\phi}}$
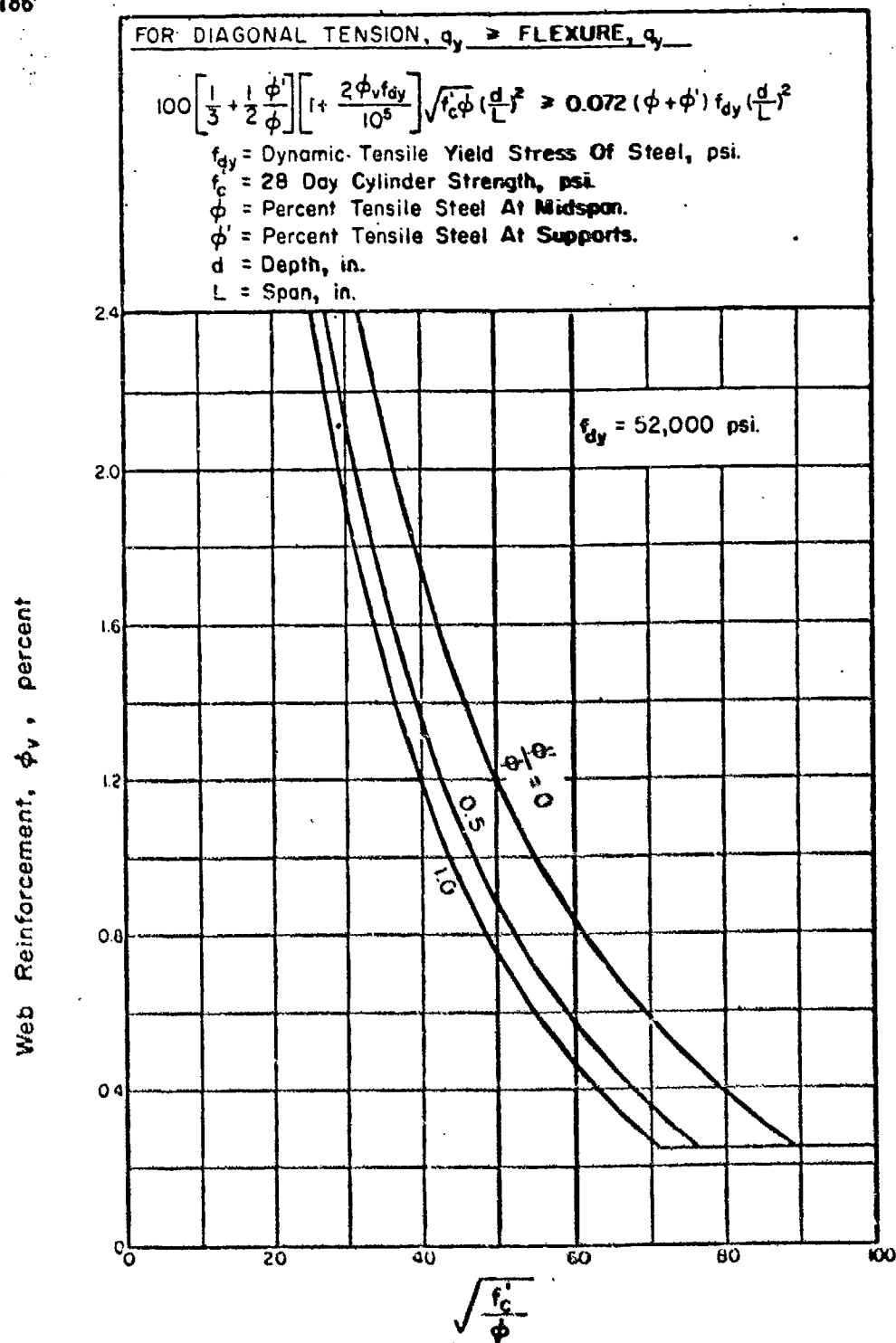
CHART 7.18   REQUIRED PERCENTAGE OF WEB REINFORCEMENT ONE-WAY REINFORCED

CONCRETE SLABS, SIMPLE OR FIXED SUPPORTS, INTERMEDIATE GRADE REINFORCEMENT

FOR FLEXURE

$$p_m = 0.090 \, (\phi_{sc} + \phi_{se}) \, f_{dy} \left(\frac{d}{L_s}\right)^2 \frac{1}{K_a^2 \phi}, \text{ psi.}$$

$$\frac{1}{K_a^2 \phi} = a \frac{\phi_{Lc} + \phi_{Le}}{\phi_{sc} + \phi_{ss}} + \frac{2-a}{3-2a}$$

f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.
ϕ_{sc} = Percent Tensile Steel, Short Span At Midspan.
ϕ_{se} = Percent Tensile Steel, Short Span At Supports.
ϕ_{Lc} = Percent Tensile Steel, Long Span At Midspan.
ϕ_{Le} = Percent Tensile Steel, Long Span At Supports.
L_L = Long Span, in.
L_s = Short Span, in.
d = Depth, in.

Note. For Simple Supports
Enter Charts With
$\phi_{se} = \phi_{Le} = 0$.

$a = \dfrac{L_s}{L_L}$

$\dfrac{\phi_{Lc} + \phi_{Le}}{\phi_{sc} + \phi_{se}} = 0.3$

0.5
0.7
1.0

f_{dy} = 44,000 psi.

$p_m = 200$ psi.
100
50

$\phi_{sc} + \phi_{se}$, percent

$\dfrac{d}{K_a \phi L_s}$

CHART 7.19 REQUIRED FLEXURAL REINFORCEMENT AND DEPTH VERSUS ($\phi_{sc} + \phi_{sc}$) FOR TWO-WAY SIMPLE

OR FIXED SUPPORT REINFORCED CONCRETE SLABS, STRUCTURAL GRADE STEEL, μ = 3

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FOR FLEXURE

$$p_m = 0.090 (\phi_{sc} + \phi_{se}) f_{dy} (\frac{d}{L_s})^2 \frac{1}{K_a^2 \phi}, \text{ psi.}$$

$$\frac{1}{K_a^2 \phi} = a \qquad \frac{\phi_{\ell c} + \phi_{\ell e}}{\phi_{sc} + \phi_{se}} + \frac{2-a}{3-2a}$$

Note: For Simple Supports
Enter Charts With
$\phi_{se} = \phi_{\ell e} = 0.$
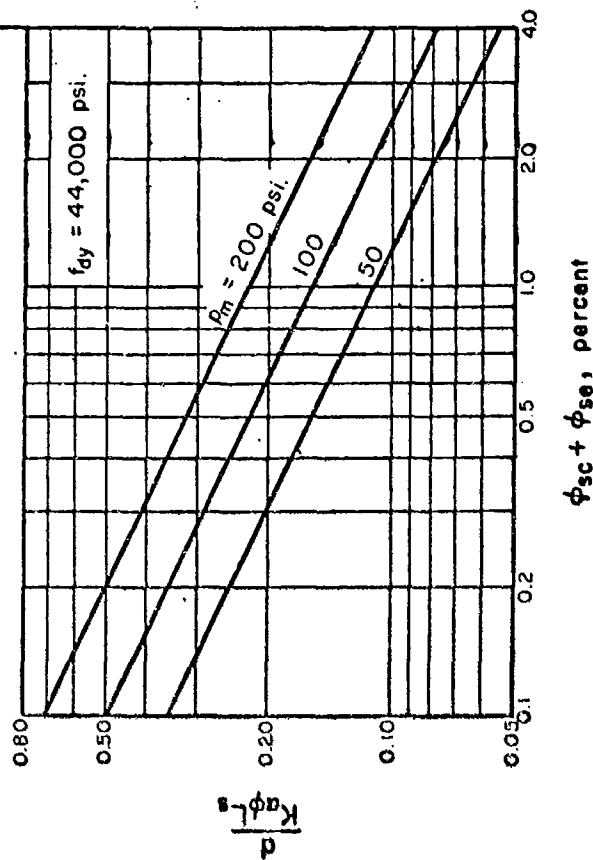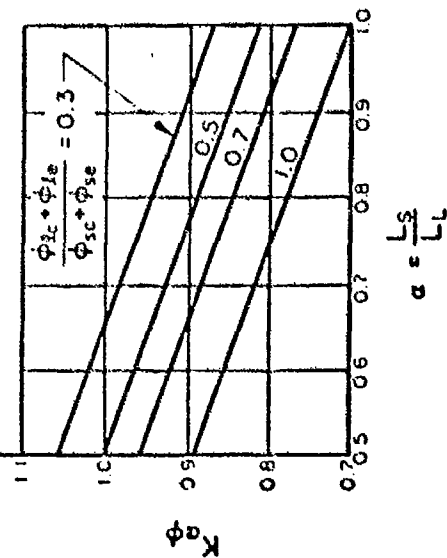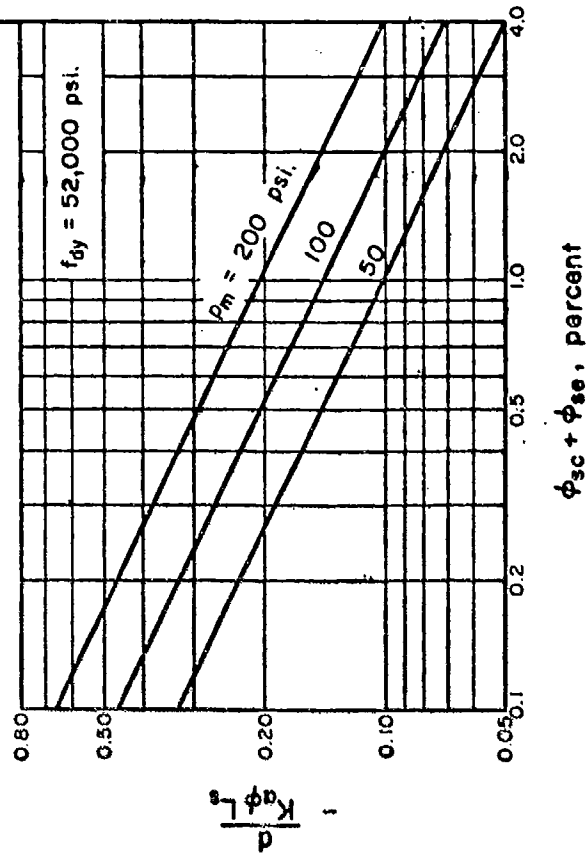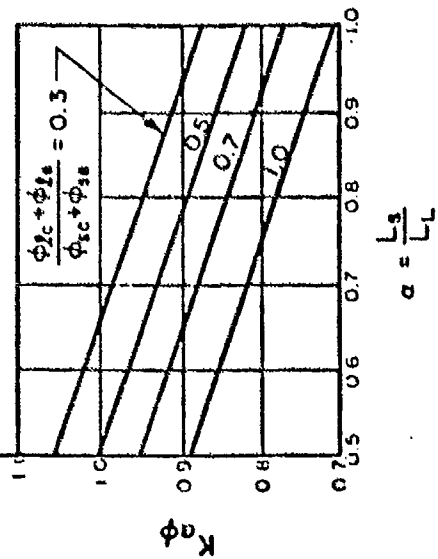
f_{dy} = Dynamic Tensile Yield Stress Of Steel, psi.
ϕ_{sc} = Percent Tensile Steel, Short Span At Midspan.
ϕ_{se} = Percent Tensile Steel, Short Span At Supports.
$\phi_{\ell c}$ = Percent Tensile Steel, Long Span At Midspan.
$\phi_{\ell e}$ = Percent Tensile Steel, Long Span At Supports.
L_L = Long Span, in.
L_s = Short Span, in.
d = Depth, in.

CHART 7.20   REQUIRED FLEXURAL REINFORCEMENT AND DEPTH VERSUS ($\phi_{sc} + \phi_{se}$) FOR TWO-WAY SIMPLE
OR FIXED SUPPORT REINFORCED CONCRETE SLABS, INTERMEDIATE GRADE STEEL, $\mu = 3$

REQUIRED WEB REINFORCEMENT, ϕ_v, percent $= AB-C$

$A = \dfrac{\frac{\phi_{1c}+\phi_{1s}}{\phi_{sc}+\phi_{ss}}\,a + \frac{2-a}{3-2a}}{\frac{2}{3}(1+a)}$

$B = \dfrac{54\left(1+\frac{\phi_{ss}}{\phi_{sc}}\right)}{\left(\frac{1}{3}+\frac{1}{2}\frac{\phi_{ss}}{\phi_{sc}}\right)\sqrt{\frac{f_c'}{\phi_{sc}}}}$

$C = \dfrac{10^6}{21 f_{dy}}$

For $f_{dy} = 44{,}000$ psi, $C = 1.14$ percent.
For $f_{dy} = 52{,}000$ psi, $C = 0.96$ percent.
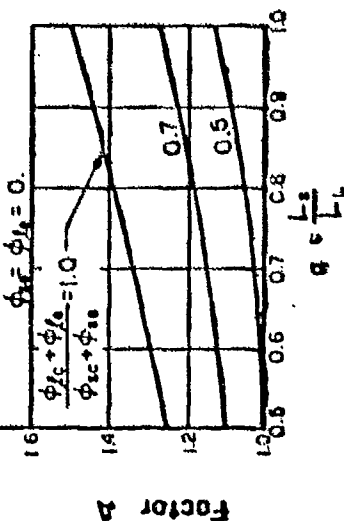
$\phi_{1c} =$ Percent Tensile Steel, Short Span At Midspan.
$\phi_{1s} =$ Percent Tensile Steel, Short Span At Supports.
$\phi_{2c} =$ Percent Tensile Steel, Long Span At Midspan.
$\phi_{2s} =$ Percent Tensile Steel, Long Span At Supports.
$f_{dy} =$ Dynamic Tensile Yield Stress Of Steel, psi.
$f_c' =$ 28 Day Cylinder Strength, psi.
$L_s =$ Short Span, in. $L_L =$ Long Span, in.

Note: For Simple Supports Enter Charts With $\phi_{1s} = \phi_{2s} = 0$.

Factor A
Factor B, percent

189
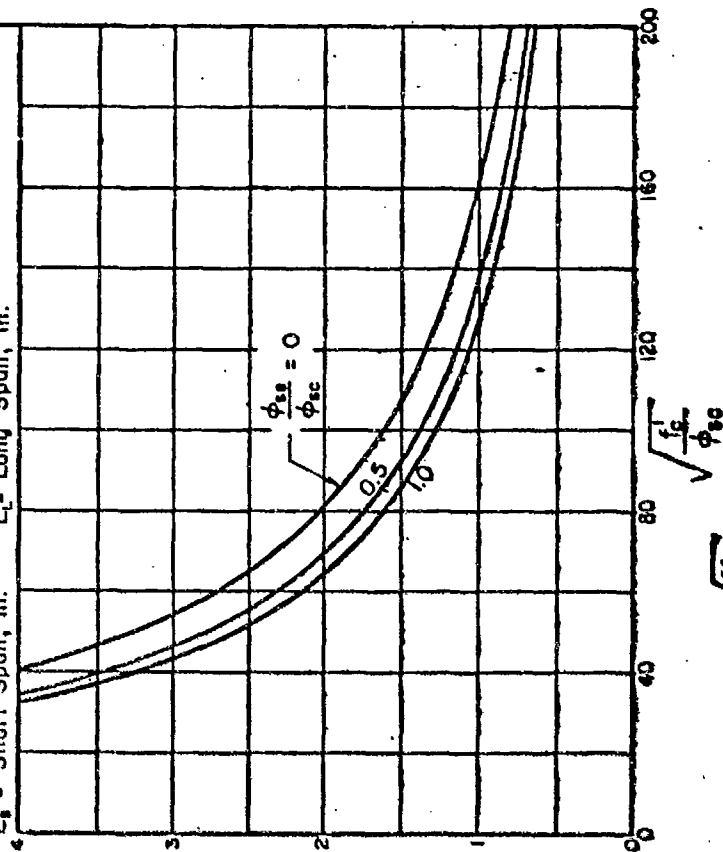
CHART 7.21 REQUIRED PERCENTAGE OF WEB REINFORCEMENT VERSUS $\sqrt{\frac{f_c'}{\phi_{sc}}}$ FOR TWO-WAY REINFORCED CONCRETE SLABS, SIMPLE AND FIXED SUPPORTS, STRUCTURAL AND INTERMEDIATE GRADE STEEL, $\mu = 0$

TABLE 7.04   CORRUGATED STEEL

PLASTIC MODULUS PER INCH WIDTH $(\frac{Z}{b})$

(Use with Charts 7.05 and 7.06)

Supplied by Multi-Plate (2 x 6 Corrugations) Corrugated Steel

Shape Factor $\frac{Z}{S}$ taken as 1.5

Gage	$\frac{Z}{b}$ In^2	W psf	A In
12	0.086	5.3	0.130
10	0.110	6.8	0.167
8	0.133	8.3	0.204
7	0.148	9.3	0.228
5	0.172	10.9	0.267
3	0.196	12.4	0.305
1	0.218	14.5	0.343

TABLE 7.05   STEEL $\mathbf{I}$ SECTIONS

PLASTIC MODULUS PER INCH WIDTH $(\frac{Z}{b})$

(Use with Charts 7.07 and 7.08)

Supplied by Rolled Steel Sections Welded Flange to Flange

$\frac{Z}{b}$ In^2	Section	W psf	Maximum q_y psi Simple[a]	Fixed[b]
3.42	10 Jr 9	40.2	721	360
3.07	10 B 11.5	35.0	442	273
2.95	6 I 17.25	58.1	1550	775
2.82	8 B 13	39.0	545	272
2.82	8 Jr 6.5	34.2	592	296
2.26	8 B 10	30.5	384	221
2.26	5 I 14.75	53.9	1660	930
2.07	6 B 12	36.0	426	213
1.92	7 Jr 5.5	31.7	694	347
1.55	4 WF 13	38.4	404	202
1.52	6 Jr 4.4	28.7	1070	535
1.45	6 B 8.5	25.9	326	163
1.43	4 I 9.5	40.7	1130	565
1.32	4 I 7.7	34.7	461	230
0.92	3 I 7.5	35.8	1410	705
0.82	3 I 5.7	29.3	437	218

Maximum Resistance. To insure response occurs in flexure of the section and not in shear or flexure of the plate, the span must be such that the flexural yield resistance is less than the maximum values given.

For $f_{dy} = 42,000$ psi, $v_{dy} = 25,000$ psi

Simple supports

$$q_y = \frac{8\, f_{dy}}{L^2} \quad \frac{Z}{b} < q_y^a \text{ max.}$$

Fixed Supports

$$q_y = \frac{16\, f_{dy}}{L^2} \quad \frac{Z}{b} < q_y^b \text{ max.}$$

TABLE 7.06 HOLLOW STEEL TUBING

PLASTIC MODULUS PER INCH WIDTH $(\frac{Z}{b})$

(Use with Charts 7.07 and 7.08)

Supplied by Steel Hollow Structural Tubing
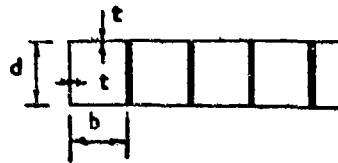
$\frac{Z}{b}$ In^2	Section d x b x t, In.	W psf	Maximum q_y psi Simple[a]	Fixed[b]
6.77	10 x 10 x 0.500	73.0	420	420
5.29	8 x 8 x 0.500	71.0	656	656
5.21	10 x 10 x 0.375	56.5	236	236
4.54	7 x 7 x 0.500	69.6	858	820
4.08	8 x 8 x 0.375	55.4	369	369
3.79	6 x 6 x 0.500	69.0	1170	980
3.57	10 x 10 x 0.250	38.7	104	104
3.53	7 x 7 x 0.375	54.4	412	482
3.53	6 x 8 x 0.500	60.9	656	595
3.37	6 x 10 x 0.500	56.0	420	396
3.05	5 x 5 x 0.500	66.5	1680	1220
2.97	6 x 6 x 0.375	54.1	657	657
2.82	8 x 8 x 0.250	38.2	164	164
2.82	5 x 7 x 0.500	59.1	858	670
2.76	6 x 8 x 0.375	47.6	369	369
2.63	6 x 10 x 0.375	44.2	236	236
2.44	7 x 7 x 0.250	37.8	214	214
2.41	5 x 5 x 0.375	52.7	944	865
2.22	5 x 7 x 0.375	46.4	482	482
2.06	6 x 6 x 0.250	37.6	292	292
2.03	4 x 8 x 0.500	51.8	656	458
1.91	6 x 8 x 0.250	33.1	164	164

TABLE 7.06 HOLLOW STEEL TUBING (CONTINUED)

$\frac{Z}{b}$ in^2	Section $d \times b \times t$, in.	W psf	Maximum q_y psi Simple[a] --	Fixed[b]
1.87	7 x 7 x 0.188	28.9	121	121
1.86	4 x 4 x 0.375	50.5	1470	1120
1.82	6 x 10 x 0.250	30.6	104	104
1.69	5 x 5 x 0.250	37.1	420	420
1.69	4 x 6 x 0.375	43.9	657	545
1.61	4 x 8 x 0.375	40.6	369	324
1.60	4 x 4 x 0.312	43.6	1020	910
1.58	6 x 6 x 0.188	28.8	164	164
1.55	5 x 7 x 0.250	32.3	214	214
1.46	6 x 8 x 0.188	25.3	92	92
1.34	3½ x 3½ x 0.312	43.5	1340	1085
1.32	4 x 4 x 0.250	36.1	656	656
1.30	5 x 5 x 0.188	28.5	236	236
1.19	5 x 7 x 0.188	24.7	121	121
1.19	4 x 6 x 0.250	30.9	292	292
1.17	3 x 5 x 0.375	40.4	944	635
1.13	4 x 8 x 0.250	28.2	164	164
1.13	3½ x 3½ x 0.250	36.0	856	825
1.06	3 x 4 x 0.312	38.1	1020	770
1.02	4 x 4 x 0.188	27.9	370	370
0.95	3 x 3 x 0.250	35.2	1170	985
0.92	4 x 6 x 0.188	23.8	164	164
0.88	3½ x 3½ x 0.188	27.9	481	481
0.88	3 x 4 x 0.250	31.5	656	590
0.87	4 x 8 x 0.188	21.6	92	92
0.84	3 x 5 x 0.250	28.9	420	396
0.76	2½ x 2½ x 0.250	34.1	1680	1210
0.75	3½ x 3½ x 0.156	23.6	334	334
0.74	3 x 3 x 0.188	27.4	657	657
0.69	3 x 4 x 0.188	24.4	370	370
0.66	3 x 5 x 0.375	22.4	236	236
0.63	3 x 3 x 0.155	23.1	448	448
0.60	2½ x 2½ x 0.188	26.8	944	865
0.584	3 x 4 x 0.156	20.6	256	256
0.532	2 x 3 x 0.250	28.4	1170	780
0.507	2 x 4 x 0.250	26.4	656	460
0.470	2½ x 2½ x 0.141	20.7	535	535
0.468	2 x 2 x 0.188	25.8	1480	1115
0.422	2 x 3 x 0.188	22.4	657	555
0.402	2 x 4 x 0.188	20.6	370	326
0.394	2 x 2 x 0.154	21.9	994	895

TABLE 7.06 HOLLOW STEEL TUBING (CONTINUED)

$\frac{z}{b}$ in^2	Section $d \times b \times t$, in.	W psf	Maximum q_y psi Simple[a]	Fixed[b]
0.341	2 x 4 x 0.155	17.3	252	252
0.331	2 x 3 x 0.141	17.3	372	372
0.330	2 x 2 x 0.125	18.2	656	656
0.295	2 x 2 x 0.110	16.1	508	508
0.151	1 x 1 x 0.133	16.9	2970	1760
0.117	1 x 1 x 0.095	13.1	1520	1150

Maximum Resistance. To insure response occurs in flexure of the section and not in shear or flexure of the plate, the span must be such that the flexural yield resistance is less than the maximum values given.

For $f_{dy} = 42,000$ psi, $v_{dy} = 25,000$ psi

Simple supports

$$q_y = \frac{8\,f_{dy}}{L^2}\,\frac{z}{b} < q_y^{a} \text{ max.}$$

Fixed Supports

$$q_y = \frac{16\,f_{dy}}{L^2}\,\frac{z}{b} < q_y^{b} \text{ max.}$$

TABLE 7.07 STEEL Q-DECK

PLASTIC MODULUS PER INCH WIDTH $(\frac{Z}{b})$

(Use with Charts 7.07 and 7.08)

Supplied by Robertson Q-Deck Sections

Type Section	Gage	$\frac{Z}{b}$ In^2	W psf	Maximum q_y psi	
				Simple	Fixed
UK	12	0.133	11.0	124	117
RK	12	0.270	12.4	141	134
FK	12	0.534	14.5	116	116
DK	12	1.13	20.4	89	89

Maximum q_y values for steel with f_{dy} = 42,000 psi, v_{dy} = 25,000 psi

TABLE 7.08   ALUMINUM I SECTIONS

PLASTIC MODULUS PER INCH WIDTH $(\frac{Z}{b})$

(Use with Charts 7.07 and 7.08)

Supplied by Rolled and Extruded Aluminum Sections Welded Flange to Flange

Shape Factor $\frac{Z}{S}$ taken as 1.1
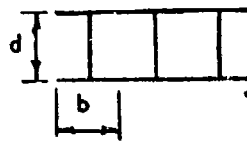
$\frac{Z}{b}$ In.^{2}	Section d x b x plf In. x In.	W psf	Maximum q_y psi	
			Simple	Fixed
2.64	S x S x 6.49	15.6	384	192
1.73	S x S x 5.366	12.9	372	186
1.48	4 x 4 x 4.76	14.3	435	217
1.10	4 x 3½ x 3.06	10.5	494	247
0.87	4 x 4½ x 2.867	7.65	212	106
0.76	4 x 3 x 1.788	7.15	374	187
0.67	4 x 2 x 1.139	6.85	620	310
0.64	2½ x 2 x 1.80	10.8	1000	500
0.462	3 x 2 x 1.001	6.0	500	250
0.366	2½ x 2 x 0.928	5.6	441	220
0.265	2 x 2 x 0.78	4.7	220	110

Maximum q_y computed for 6061 T6 Alloy

$$f_{dy} = 40,000 \text{ psi}$$

$$v_{dy} = 23,000 \text{ psi}$$

CHAPTER 8. DESIGN PROCEDURE

8.01 INTRODUCTION

A general design procedure based on the material of the preceding chapters is presented in this chapter. In Chapter 9, an illustrative example using this design procedure is developed.

From the discussions in previous chapters it is obvious that the architectural layout, radiation shielding protection, and blast resistance of the entranceway are all to some degree interdependent and generally can not be considered separately. In a large measure the geometrical configuration and dimensions of an entrance structure are determined by considerations such as shelter capacity, entry flow rates, the terrain, the elevation of the floor with respect to the ground surface, existing structures and utilities, safety considerations, etc.

Once a preliminary configuration has been qualitatively determined to satisfy these architectural considerations, a preliminary check of radiation shielding requirements should then be made to refine further the entrance configuration before a detailed shielding analysis is performed and before the structural analysis is made for blast resistance. It is recommended that the radiation inputs be considered in the following order: prompt neutron radiation, prompt gamma radiation, and fallout gamma radiation. In all likelihood some modification in corridor lengths, number and location of bends, and in barrier shielding may be required.

The design of the blast door (or doors) is a function of location and orientation which determines the maximum pressure to which they are subjected, of the material from which they are fabricated, of the support conditions, and of the spans. The location of the door or doors is dependent upon several factors, primarily the terrain conditions, the possible require-ment for an interlock, and the exclusion of fallout deposition within the entrance structure. Normally the radiation shielding protection (i.e., reduction factor) afforded by the door itself is small and therefore is neglected in the shielding computations of this report.

In the general design procedure, the steps are therefore:

1. Input data

2. Architectural layout design

    3. Radiation shielding design

    4. Blast resistant design

8.02 INPUT DATA

The designer must be provided with the following input data or is required to make assumptions on these items.

1) Architectural Considerations

    a. Terrain configuration (slopes, elevations, etc.)

    b. Depth of shelter floor from ground surface

    c. Existing adjacent buildings and/or utility line locations

    d. Shelter capacity

    e. Requirements for interlock (capacity and location)

    f. Entry flow rates

    g. Building codes requirements

2) Weapons Effects Considerations

    a. Design pressure and weapon yield

    b. Outside levels of radiation dose (prompt neutron, prompt gamma, and residual gamma)

    c. Acceptable total radiation dose within shelter proper (prompt neutron, prompt gamma, plus residual gamma)

3) Preliminary Design Assumptions. For preliminary design, assumptions must be made as follows:

    a. Proportions of acceptable total radiation dose admitted through entranceway and shelter proper

    b. Contributions of prompt neutron, prompt gamma and residual gamma radiation admitted through entranceways

As a result of the preliminary design, other proportions may be more acceptable as long as the total is less than the permissible total.

8.03 PRELIMINARY CONFIGURATION

The preliminary entranceway configuration is dependent upon both the architectural considerations enumerated above and the preliminary radiation shielding calculations for the worst case orientation of the weapon with respect to the entranceway.

1) Architectural Considerations. A preliminary entranceway configuration is determined based on the architectural considerations

enumerated above, i.e., terrain, depth of shelter floor, existing buildings
and utilities, shelter capacity, etc.

2) <u>Preliminary Radiation Shielding Calculations</u>. To assist in
making a preliminary entrance configuration for further detailed analysis,
it is recommended that the prompt neutron radiation be considered first.
In order to do this the worst case orientation of the weapon with
respect to the entranceway must be determined.

    a. Compute solid angle fractions required for
         shielding calculations.

    b. Determine worst-case orientation for prompt nuclear
         radiation.

    c. Calculate reduction factor required for prompt neutrons.

$$R_f = \frac{\text{allowable prompt neutron dose}}{\text{outside prompt neutron dose}} = \frac{D_i}{D_o}$$

         This reduction factor may be obtained by means of barriers
         and/or geometry (corridor lengths). Corridor bends have
         only a negligible effect upon neutron attenuation.

    d. <u>Geometry</u>. From Chart 6.01, it is apparent that a geometry
         reduction factor, R_e, of about 0.2,   is the best
         that can be obtained in the first leg of the entrance
         corridor. Beyond that point if further reduction in
         neutron intensity is required, it can be obtained by length
         of corridor and/or by the provision of a barrier wall just
         inside the shelter proper.

    e. <u>Barrier</u>. By reference to Chart 6.03, a concrete wall with
         a mass thickness of 100 psf (about 8") will provide a
         barrier reduction factor, $B(X)$, of 10^{-1}; a mass thickness
         of 200 psf (about 16" of concrete) will provide a barrier
         reduction of about 10^{-2}.

    f. <u>Corridor Length</u>. If the entire reduction factor were
         to be achieved by corridor length, the number of half-
         lengths required beyond the first 90° bend may be
         calculated as follows:

$$R_c = R_f = \left(\frac{1}{2}\right)^n$$

         where n = number of half-lengths. (See Section 6.04.)

g. <u>Corridor Length and Barrier</u>. If a combination of corridor
    length and barrier reduction is possible or desirable,
    the number of half-lengths is obtained as follows:

$$R_f = R_e \times R_c \times B(X)$$

where R_f = overall entrance reduction factor

R_e = entrance reduction facotr

R_c = corridor reduction factor

$B(X)$ = barrier reduction factor

$$R_c = \frac{R_f}{R_e \times B(X)} = \left(\frac{1}{2}\right)^n$$

8.04 RADIATION SHIELDING ANALYSIS

Following the preliminary determination as to entrance length
and configuration the following analyses should be made in sequence.

1) Calculate the prompt neutron contribution admitted through
the entrance opening.

2) Calculate the prompt neutron contribution admitted through
the roof slabs and walls of the entrance structure.

3) Preliminary check: the sum of the first two calculations,
1) and 2), should be about half the "allowable" prompt radiation dose.

4) Calculate the prompt gamma contribution admitted through the
entrance opening.

5) Calculate the prompt gamma contribution admitted through the
roof slabs and walls of the entrance structure.

6) Calculate the secondary gamma ray contribution due to neutron
absorption in the entrance corridor walls. (The present report gives no
information on how to do this. The inclusion of this item is based on the
assumption that future investigations will provide such a means.)

7) Preliminary check: the sum of calculations 4) and 5) should
be less than half the "allowable" prompt radiation dose.

8) Calculate the residual gamma contribution admitted through the entrance opening.

9) Calculate the residual gamma contribution admitted through the roof slab and walls of the entrance structure.

10) Add the contributions calculated in steps 1), 2), 4), 5), 8) and 9). The total should be less than the "allowable" dose admitted through the entrance structure. At this time adjustments can be made in the original design as required to meet the criteria established or the criteria might be revised in light of the attenuations possible from the complete design. Having performed the preceding calculations it should be clear as to what effect the lengthening or shortening the entrance corridor and the addition or deletion of mass thickness in various barriers will have on the total contribution received through the entrance structure. Economic considerations will dictate what changes are made in the previously established criteria as to the proportioning of dose through the entrance-way and the shelter proper and in the design of the entranceway structure.

8.05 BLAST RESISTANT DESIGN

The following procedure is used to design the various structural elements of the entranceway structure, including the walls adjacent to the open stairwell, the stair slab, the landings, the interior stairs, and the corridors:

1) _Pressures_. Determine the pressures to which the various structural elements will be subjected. This pressure will be a function of the location of the element and its orientation with respect to the blast wave.

2) _Properties_. Determine the properties of the various materials that will be used, e.g., soil properties, concrete properties, reinforcing steel properties, etc.

3) _Loadings_. Determine the loadings on the various structural elements.

4) _Flexural Resistance_. Determine the required flexural resistance of the various structural elements and the section required to provide such resistance.

5) <u>Diagonal Tension and Shear</u>. To insure ductile behavior, the yield resistance for diagonal tension and pure shear must exceed the flexural yield resistance.

6) <u>Ultimate Deflection</u>. Determine the ultimate deflection of members acting against the backfill under loading in order to calculate the required resistance.

8.06 BLAST RESISTANT DESIGN (CHARTS)

In many cases the design of the structural elements of the entranceway structure may be done more expeditiously by the use of the Design Charts of Chapter 7. For illustrative purposes, the following design procedure for the door element using the charts is presented:

1) Depending upon the orientation of the door (i.e., flush at the surface, not flush at the surface, or within the entrance corridor), select the design pressure.

2) Select the type element (i.e., flat steel plate, corrugated steel plate, built-up steel section, aluminum section, reinforced concrete slab, solid timber section, plywood plate, or built-up plywood section).

3) Select the following design parameters:

    a. One-way or two-way span, simple or fixed supports, L, or L_s and L_ℓ.

    b. Design stresses (f_{dy} and v_{dy}).

    c. Ductility factor for structural integrity, (μ).

    d. Clearance requirements on deflection.

4) Determine thickness of section required from Charts and Tables.

5) Check design for shear from Tables.

6) Check clearance requirements. If required, revise μ as required and obtain new section, Step 4), and check shear, Step 5).

CHAPTER 9.   ILLUSTRATIVE DESIGN EXAMPLE

9.01   INTRODUCTION

In this chapter is presented a design example illustrating the use of the design procedure of Chapter 8 and the technical material contained in the preceding chapters.

The design example is included for illustrative purposes only. The input data assumptions and the assumed radiation dose criteria are not to be considered as standard criteria. In an actual entranceway design, local site and soil conditions, population distribution, radiation dose criteria, etc., would have to be obtained from architectural, engineering, and/or civil defense organizations.

9.02   INPUT DATA

1)   Architectural Considerations.

a.   Terrain; level

b.   Depth of shelter floor from ground surface; 12 ft.

c.   Existing adjacent buildings and/or utility lines; (not pertinent to example design)

d.   Shelter capacity; 800 persons

e.   Interlock requirements: assume none

f.   Entry flow rate required:

Given: Warning time; 15 min.

Button-up time; 3 min.

Total entry time; 12 min.

The hypothetical area to be served by the shelter is assumed to be a 50 acre, suburban, residential area with a total population of 800 persons, uniformly distributed (Fig. 9.01). The actual arrival rate at the shelter entrance as a function of time is dependent upon many variables including the state of readiness of the shelterees, the distances they have to travel to reach the shelter, the ages and physical condition of the people involved, etc. In a specific instance some of these variables can be identified and evaluated.

For the purpose of this problem, the arrival
rate was assumed to be primarily a function of the
distances the people would have to travel to reach
the shelter entrance. The area was divided into
subareas and it was assumed that those closest to the
shelter could reach the entrance in an average of two
minutes. The results of the calculations are
tabulated below and plotted in Fig. 9.02.

Subarea	No. Persons	Average Time of Arrival (min.)
1	40	2
2	120	4
3	200	6
4	280	8
5	160	10
Total	800	

Based on the histogram, Fig. 9.02, a peak
entrance flow rate and an average entrance flow rate
of 120 and 80 persons per minute, respectively, are
considered adequate. These rates correspond to standard
entrance rates for a 2 unit stairway (4ft.wide). Note
that the next smaller unit, a 1.5 unit stairway, is not
adequate to admit this population in the time interval
assumed.

2) Weapons Effects Considerations.

    a. Design overpressure and weapon yield; 50 psi and 1 MT,
respectively.

    b. Outside levels of radiation dose;

        Prompt Neutron; to be determined.

        Prompt Gamma; to be determined

        Residual Gamma; 93,000 rad

    c. Acceptable levels of radiation doses within shelter;

        Prompt Neutron and Prompt Gamma; 20 rad

        Residual Gamma; 20 rad

These "acceptable" doses are only assumed values
for this example problem and do not reflect criteria.

3) Preliminary Design Assumptions. It has been assumed in the
following example problem that half of the total dose (40 rads) would be
received through the shelter proper and half through the entrance system.
It has been further assumed that the 20 rads received through the entrance
system is divided equally between prompt and residual. These may be
summarized as follows:

Through Shelter Proper		20 Rads
Through Entrance System		
Prompt	10	
Residual	10	
		20
Total Dose		40 Rads

These proportions will vary with a given shelter and entrance.
The final proportions will depend upon the relative cost of the entrance
system vs. the shelter proper.

9.03 PRELIMINARY CONFIGURATION

1) Architectural Considerations.

(a) General. Based on the preceding discussion, it is
assumed that:

1. the entrance structure must provide a change in
   elevation of about 12 ft.
2. the cross-sectional dimensions of the corridor
   are 4' x 7'
3. no interlock is required; therefore, the blast
   door will be placed at the shelter end of the
   corridor.

(b) Surface Transition Element. For the purpose of this
example it is assumed that the shelter is located in a school yard or small
park so that there is no danger of a significant amount of debris in the
entrance. Further, since the terrain is flat, an open entrance (with a
railing) is used to avoid the reflection of the shock wave which would occur

from the housing over a covered entrance.

        (c) <u>Depth Element</u>. To avoid an unnecessarily long entrance corridor in the flat terrain, stairs are used rather than a ramp. According to criteria discussed in Chapter 3, the stairs have a tread of 9 1/2" and a riser of 7 3/4". The maximum height between landings should not exceed 8' 6". Since a corridor height of 7' 0" is required, and, since a cover over the landing is required for blast and radiation protection, the first flight of stairs should approach the maximum (8' 6").

        (d) <u>Radiation Shielding Considerations</u>. The following basic principles of radiation shielding design of shelter entrance structures must be considered:

        1. The riser element should be designed to obtain maximum cover over as much of the entrance corridor as possible.

        2. The legs of a tortuous entrance corridor should be of approximately equal length to maximize the reduction factor for prompt gamma radiation for a given total length of corridor.

        3. Turning the entrance corridor through 90° is more effective in reducing prompt gamma radiation than adding an equivalent length of straight corridor.

    2) <u>Preliminary Configuration</u>. Based on the preceding brief considerations, a preliminary entrance configuration is depicted in Figs. 9.03, 9.04 and 9.05. The slab thicknesses may have to be changed after considering the blast loads.

    3) <u>Preliminary Radiation Shielding Calculations</u>.

        (a) <u>Compute Solid Angle Fractions Required for Shielding Calculations</u>. (Figs. 9.03, 9.04, 9.05 and 9.06).

        (i) <u>Calculate solid angle fraction subtended by opening at Point 1</u>.

$$Z = \frac{4.0}{\cos \theta_1} \cos \left(\frac{\theta_2 - \theta_1}{2}\right) = 4.92 \text{ ft.}$$

$$L = 2(\frac{4}{\cos \theta_1}) \sin (\frac{\theta_2 - \theta_1}{2}) = 2.78 \text{ ft.}$$

$$W_{max} = 4 \text{ ft.}$$

$$W_{min} = 2 \tan (\frac{\theta_{min}}{2}) \left[\frac{4}{\cos \theta_1} \cos (90^\circ - \theta_2) \right] = 1.34 \text{ ft.}$$

$$\text{Use } W_{ave} = \frac{W_{max} + W_{min}}{2} = 2.67 \text{ ft.}$$

$$\text{Therefore, } e = \frac{W}{L} = \frac{2.67}{2.78} = 0.97$$

$$\text{and } n = \frac{2Z}{L} = \frac{2 (4.92)}{2.78} = 3.54$$

From Chart 3, Ref. 6.02, $\omega_1 = 0.05$

(2) <u>Calculate solid angle fraction at Point 2.</u>

Assume $W = 4$ ft. and $L = 7$ ft.

Compute Z (locate Point 2 at $3'-10\frac{1}{4}''$ above floor to simplify calculations)

$$\theta_1 = \text{arc tan } \frac{7}{8.67} = 39^\circ$$

$$Z_2 = \cos (\frac{\theta_1}{2}) \frac{8.67}{\cos \theta_1} = 10.5 \text{ ft.}$$

Then, $e = 0.57$ and $n = 3.00$

From Chart 3, Ref. 6.02, $\omega_2 = 0.04$

(3) <u>Calculate solid angle fractions at Points 3 and 4.</u>

ω	W	L	Z	e	n	ω
ω_3	4	7	9	0.57	2.57	0.05
ω_4	4	7	3	0.57	0.86	0.29

(b) <u>Determine Worst-Case Orientation for Prompt Nuclear Radiation.</u> There are two cases which should be investigated.

Case 1. The weapon can be "seen" from Point 1
          through the entrance opening.

Case 2. The weapon can be "seen" from Point 2
          through the slab over the landing.

(1) Neutron Radiation. The reduction factor for neutrons
     at Point 4 for the two cases may be written
     (subscripts indicate cases);

$$R_{f1} = R_{e1} \times R_{c1}$$

$$R_{f2} = R_{b2} \times R_{e2} \times R_{c2}$$

where R_e = entrance reduction factor

R_c = corridor reduction factor

R_b = barrier reduction factor

R_e is a function of the solid angle fraction
subtended by the opening at the point of interest.

R_c is a function of the length of corridor beyond
the point of interest.

Case 1. From Chart 6.01 (since $\omega_1 = 0.05$)

$R_{e1} = 0.28$, say 0.3 (for neutrons)

$R_c = (\frac{1}{2})^n$

where $n = \dfrac{L}{L_{1/2}} = \dfrac{10'-8'' + 9'-0'' + 3'-0''}{L_{1/2}} = \dfrac{22'-8''}{L_{1/2}}$

and $L_{1/2} = 0.366 (W + L) = 0.366 (4 + 7) = 4.03$ ft.

Then $R_c = (\frac{1}{2})^{5.64} = 0.020$

Therefore, $R_{f1} = (0.3)(0.020) = 6.0 \times 10^{-3}$

Case 2. Can not use ω_2 for R_{e2} because the slab
subtends a much smaller solid angle fraction.

$\theta_2 = \text{arc tan} \dfrac{7}{12.67} = 28.9°$

$$\theta_3 = \text{arc } \tan \frac{7}{6.75} = 46.1^\circ$$

$$\frac{1}{2}(\theta_3 - \theta_2) = 8.6^\circ$$

$$W = 2\left[\frac{8.67}{\cos \theta_3}(\sin 8.6^\circ)\right] = 3.72 \text{ ft.}$$

$$L = 4 \text{ ft.}$$

$$Z = \cos 8.6^\circ\left[\frac{8.67}{\cos \theta_3}\right] = 12.3 \text{ ft.}$$

Then $e = 0.93$, $n = 6.15$ and $\omega_{e2} = 0.012$

From Chart 6.01, $R_{e2} = 0.13$

$$R_{c2} = (\tfrac{1}{2})^n, \text{ where } n = \frac{L}{L_{1/2}} = \frac{9'-0'' + 3'-0''}{4.03} = 2.97$$

$$R_{c2} = 0.13$$

For a mass thickness of 175 psf ($14''$ concrete)
and angle of incidence of between 28.9° and 46.1°,
R_{b2} (175 psf) $\tilde{=} 0.1$ from Chart 6.04.

Therefore, $R_{f2} = (0.1)(0.13)(0.13) = 1.69 \times 10^{-3}$

Comparing R_{f1} and R_{f2}, Case 1 is the worst
case orientation for neutrons.

(2) Gamma Radiation.

$$R_{f1} = R_{e1}(0.1 \omega_2)(0.5 \omega_3)(0.5 \omega_4), \text{ and}$$

$$R_{f2} = R_{e2}R_{b2}(0.1 \omega_3)(0.5 \omega_4)$$

Since the factor $(\omega_3)(0.5 \omega_4)$ is common, it may
be omitted and $R_{f1}: 0.05 R_{e1}(\omega_2)$

$$R_{f2}: 0.1 R_{e2} \times R_{b2}$$

From previous calculations and from Charts 6.01
and 6.02: $R_{f1}: 0.05 (0.58)(0.04) = 1.16 \times 10^{-3}$

$$R_{f2}: 0.1 (0.39)(0.032) = 1.25 \times 10^{-3}$$

Comparing R_{f1} and R_{f2} it is apparent that Case 2 is the worst case orientation for prompt gamma. However, the difference is not great and can easily be made up by increasing the mass thickness of the slab over the landing.

What mass thickness is required to make $R_{f2} = R_{f1}$ for prompt gamma?

$$R_{f2} = (0.1)(0.39) R_{b2} = 1.16 \times 10^{-5}$$

or $R_{b2} = 2.97 \times 10^{-2}$

From Chart 6.02, for 30° angle of incidence, a barrier factor of 0.0297 is obtained by a mass thickness of about 180 psf.

Use Case 1 as worst-case orientation.

(c) Prompt Radiation - Worst Case. Since 50 psi exists at a horizontal range of about 4,700 ft. from the point of detonation of a one MT weapon, the slant range of the shelter entrance from that point is:

$$R = \frac{4,700}{\cos\left[90 - \theta_1 - \frac{(\theta_2 - \theta_1)}{2}\right]} = 5600 \text{ ft.}$$

The prompt nuclear radiation dose outside at this slant range is (Ref. 5.01):

          Prompt gamma   - 11,800 rads

          Prompt neutron -   750 rads

Note: Conversion factor; 1 neutron/square centimeter equals 1.8×10^{-9} rad (Art. 11.87, Ref. 5.01)

Sec. 9.03

(d) <u>Calculate Reduction Factor Required for Prompt
Neutrons.</u> For a first approximation it is assumed
that half of the "allowable" prompt dose through the
entrance is contributed by neutrons. Then the
reduction factor required for prompt neutron is:

$$R_f = \frac{5}{750} = 0.00667$$

(e) <u>Corridor Length Required for Neutrons.</u> (No barrier
inside shelter).

$$R_c = \frac{R_f}{R_e} = \left(\frac{1}{2}\right)^n$$

$$R_c = \frac{0.00667}{0.3} = 0.0222$$

Therefore, $n \approx 6$ half-lengths

L = 6 × 4.03 = 24.2 ft. required

Length of second leg = 10 ft.

Length of third leg = 11 ft.

Length of fourth leg = 5 ft.

26 ft. > 24.2 ft.

Note that for neutron attenuation the length along the
center-line of the tunnel between the points of interest
is used. The total length of corridor required could
be reduced by providing a barrier wall inside the
shelter proper. If an 8" concrete wall were provided
just inside the shelter (beyond the blast door), the
equation for the total reduction factor becomes:

$$R_f = R_e \times R_c \times R_b$$

where R_b (100 psf) = 0.1 (Chart 6.03)

$$R_c = \frac{0.00667}{(0.3)\,(0.1)} = 0.222 = \left(\frac{1}{2}\right)^n$$

Therefore, n = 2.2

Total length = 2.2 × 4.03 $\approx$ 9 ft.

The installation of such a barrier would eliminate
the necessity for the third and fourth legs insofar
as the neutron contribution is concerned. The
shelter entrance would then appear as shown in
Fig. 9.07. Although the space between the barrier
wall and the blast door cannot be occupied initially,
it may be possible to use this area after some time
has elapsed. A cost comparison then would involve
the cost of the third and fourth legs in Fig. 9.03
versus the cost of the unusable shelter area plus
the barrier wall in Fig. 9.07.

For this example it has been assumed that the basic
configuration (Fig. 9.03) is less costly.

9.04 RADIATION SHIELDING ANALYSIS

1) <u>Prompt Neutron Dose through Entrance Opening</u>. From previous
calculations

$$R_f = R_e \times R_c = (0.3)(\tfrac{1}{2})^6 = 0.00468$$

$$D_i = R_f \times D_o = (0.00468)(750) = 3.5 \text{ rads at Point 4}$$

where D_i = inside dose at Point 4

D_o = outside dose

2) <u>Prompt Neutron Dose through Roof and Walls</u>.

(a) <u>Slab over Point 1</u>.

(i) <u>Barrier Reduction Factor</u>. If the slab over the
landing were infinite in extent the barrier
reduction afforded by the slab at Point 1 can be
determined. The fact that the slab is not
infinite would make the barrier more effective.
From Chart 6.04 the Barrier Reduction Factor for
14 MeV neutrons is

$$R_b (180 \text{ psf}) = 0.18 \text{ for } 90^o \text{ incidence}$$

$$R_b (180 \text{ psf}) = 0.02 \text{ for } 0^o \text{ incidence}$$

The actual angle of incidence for the assumed

point of detonation is $\left[\theta_1 - (\frac{\theta_2 + \theta_1}{2})\right]$ or about

35°.

<u>Use</u> R_b (180 psf) $= 0.1$ for 35° incidence.

(2) <u>Corridor Reduction between Points 1 and 4.</u>

$R_c = (\frac{1}{2})^6 = 0.016$

(3) <u>Contribution through Slab over Point 1.</u>

$R_f = R_b \times R_c = 0.0016$

$D_i = R_f \times D_o = 0.0016 \, (750) = 1.2$ rads at Point 4

(b) <u>Slab over Point 2.</u>

(1) <u>Barrier Reduction Factor.</u>

Concrete $= 175$ psf

Soil 100 pcf $\times$ 3.83 ft. $= \underline{383}$ psf

$\qquad\qquad\qquad\qquad\qquad$ 558 psf, say 560 psf

From Chart 6.04, (14 MeV)

R_b (560 psf) $= 0.001$ for 90° incidence

R_b (560 psf) $= 0.00013$ for 0° incidence

Use R_b (560 psf) $= 0.0005$ for 35° incidence

(2) <u>Corridor Reduction between Points 2 and 4.</u>

$n = \frac{16}{4.03} = 4$; and $R_c = 0.062$

(3) <u>Contribution through Slab and Soil over Point 2.</u>

$R_f = R_b \times R_c = 5 \times 10^{-4} \times 6.2 \times 10^{-2} = 3.1 \times 10^{-5}$

$D_i = R_f \times D_o =$ negligible dose at Point 4

(c) <u>Wall Contribution.</u> The only wall contribution of
significance is the contribution through the wall between
the first and third legs. For the assumed orientation
(0°) and an infinite plane barrier (i.e., assuming

the walls between these legs to be infinite in length and width), from Chart 6.04 the barrier reduction factor at Point 3 is

$$X = (2' \ 4'' \ concrete)(150 \ pcf) + (4' \ 4'' \ earth)$$
$$(100 \ pcf) \cong 780 \ psf$$
$$R_b \ (780 \ psf) = 1.0 \times 10^{-5}$$
$$R_c = 0.5 \ (from \ Point \ 3 \ to \ Point \ 4)$$

Therefore, $R_f = R_b \times R_c = 5 \times 10^{-6}$

$D_i = R_f \times D_o =$ negligible dose at Point 4

3) **Preliminary Check, Neutron Contribution.** Adding the contributions:

through entrance: 3.5 rads

through roof slab: 1.2 rads

Total neutron $D_i = $ 4.7 rads at Point 4

This sum should be $\leq$ 5 rads.

4) **Prompt Gamma Dose through Entrance Opening.**

$$R_f = R_e \times R_1 \times R_2 \times R_3$$

where R_f = total reduction factor

R_e = entrance reduction factor

R_n = reduction due to n^{th} 90° bend

$$R_f = R_e \ (0.1 \ \omega_2)(0.5 \ \omega_3)(0.5 \ \omega_4)$$

(See Fig. 9.03 for designation of solid angle fractions.)

$$R_f = 0.025 \ R_e \ (\omega_2)(\omega_3)(\omega_4)$$

ω	W	L	Z	e	n	ω
ω_2	4	7	10	0.57	2.85	0.04
ω_3	4	7	9	0.57	2.57	0.05
ω_4	4	7	3	0.57	0.86	0.29

From previous calculations, $\omega_1 = 0.05$

From Chart 6.01, $R_e = 0.6$

Therefore, $R_f = 0.025 \ (0.6)(0.04)(0.05)(0.29) = 0.87 \times 10^{-5}$

$D_i = R_f \times D_o = 0.87 \times 10^{-5} \times 1.18 \times 10^4$

$D_i = 0.1$ rads at Point 4

5) Prompt Gamma Dose through Roof and Walls.

(a) Slab over Point 1. Assume no geometry reduction, i.e., a plane barrier of mass thickness X_o in the z-direction and infinite in the x-y plane.

From Chart 6.02, $R_b (180 \ psf) = 2.90 \times 10^{-2}$ for 30° incidence

Therefore, $R_f = R_b \ (0.1 \ \omega_2)(0.5 \ \omega_3)(0.5 \ \omega_4) = 4.23 \times 10^{-7}$

$D_i = R_f \times D_o = 4.23 \times 10^{-7} \times 1.18 \times 10^4$

= negligible dose at Point 4

(b) Slab and Soil over Point 2.

From Chart 6.02, $R_b (560 \ psf) = 3 \times 10^{-5}$ for 30° incidence

Therefore, $R_f = R_b \ (0.1 \ \omega_3)(0.5 \ \omega_4)$

D_i = negligible dose at Point 4

(c) Slab and Soil over Point 3.

$R_f = R_b \ (0.1 \ \omega_4) = 3 \times 10^{-5} \times 0.1 \times 0.29$

$R_f = 9.7 \times 10^{-7}$

D_i = negligible dose at Point 4

(d) Contribution through Walls.

Negligible dose at Point 4

6) Secondary Gamma Ray Contribution from Corridor Walls. This section is included to make the outline complete. In lieu of an available procedure for such calculation, it is assumed for the sake of the illustrative problem that the hazard has been eliminated by a boron containing chemical on the walls and/or that a degree of conservatism in handling other aspects of the problem is adequate to take care of the matter.

7) Preliminary Check, Total Prompt.

Dose admitted through entrance structure:

Neutron ~ 4.7 rads

Gamma ~ 0.1 rads

Total   4.8 rads at Point 4; this total should

be $\leq$ 10 rads.

Note that if the fourth leg of the corridor were omitted the prompt neutron dose would be increased by about a factor of 2 since one half-length = 4.03 ft. In addition, the prompt gamma dose would be increased by a factor of $\frac{1}{0.5\,\omega_4}$, or about 7. Therefore, at this stage it appears that the fourth leg is not required to meet the total prompt dose assumed. However, depending on the dimensions and orientation of the shelter, this fourth leg may be required soley to connect the entrance to the shelter.

8) Residual Gamma Contribution through Entrance Opening. It is assumed that the contamination is uniformly distributed on horizontal projections of all surfaces. In addition, it is assumed that the landing and the floor below the grating are similarly contaminated despite the fact that the slab overhead protects them to some extent.

(a) Skyshine Contribution at Point 1.

ω_1 = 0.05

From Chart 10, Case 3, Ref. 6.02, A_a = 0.0021

(b) Contribution at Point 1 from Contamination below Grating. (Fig. 9.08). Treat as a contribution from a roof with X_o = 0 psf.

$C_g = C_g\ (\omega_{\ell g},\ 0\ \text{psf})$

where C_g = contribution from below grating

W = 4 ft. = L

Z = 4 ft.

e = 1 and n = 2

From Chart 3, Ref. 6.02, $\omega_{\ell g} = 0.13$

From Chart 4, Ref. 6.02, $C_g = C_g (0.13, 0 \text{ psf}) = 0.024$

(c) <u>Contribution at Point 1 from Contamination on Landing.</u> (Fig. 9.08). Treat as contribution from roof with $X_o = 0$ psf.

$$C_\ell = \frac{1}{2} \left[C_\ell (\omega_{\ell 2}, 0 \text{ psf}) - C_\ell (\omega_{\ell 1}, 0 \text{ psf}) \right]$$

where C_ℓ = contribution from landing

ω	W	L	Z	e	n	ω	C_ℓ
$\omega_{\ell 2}$	4	9.83	3	0.407	0.61	0.32	0.070
$\omega_{\ell 1}$	4	4	3	1	1.5	0.20	0.042

Therefore, $C_\ell = \frac{1}{2} \left[0.070 - 0.042 \right] = 0.014$

(d) <u>Contribution at Point 1 from Contamination on Stairs.</u> (Fig. 9.09). The limited strips of contamination on the stairs are too small to compute directly as in the previous fashion. Therefore, to obtain the contribution from the contamination on the stairs it is recommended that the plane of the detector be rotated so that it is parallel to an idealized plane through the stairs. If the shielding afforded by the edges of the top steps is ignored the contribution from these steps will be exaggerated. Using this conservative approach, the ground direct contribution from the contamination on the stairs may be calculated as follows. Treat as contribution from roof with $X_o = 0$ psf.

$$C_s = \frac{1}{2} \left[C_s (\omega_{s2}, 0 \text{ psf}) - C_s (\omega_{s1}, 0 \text{ psf}) \right]$$

where C_s = contribution from stairs

$$\theta = \text{arc tan } \frac{4'-11''}{3'} = 58.6^\circ$$

$$\varphi = \theta - 39.2^\circ = 19.4^\circ$$

$$Z = \frac{4.92}{\sin 58.6^\circ} \ (\cos 19.4^\circ) = 5.42 \text{ ft.}$$

$$W_1 = 2(\frac{4.92}{\sin 58.6^\circ}) \ \sin 19.4^\circ = 3.83 \text{ ft.}$$

$$L_2 = 3.83 + 2 \ (\frac{9.5}{\cos 39.2}) = 28.3 \text{ ft.}$$

ω	W	L	Z	e	n	ω	C_s
ω_{s2}	4	28.3	5.42	0.14	0.385	0.20	0.042
ω_{s1}	3.83	4	5.42	0.96	2.72	0.08	0.015

$$C_s = \frac{1}{2} \ (0.042 - 0.015) = 0.014$$

(e) Total Residual Contribution at Point 1.

$$C_{T1} = A_a + C_g + C_\ell + C_s$$

$$C_{T1} = 0.054$$

(f) Dose at Point 4.

$$R_{f1} = C_{T1} \ (0.1 \ \omega_2)(0.5 \ \omega_3)(0.5 \ \omega_4)$$

$$R_{f1} = 0.025 \ C_{T1} \ (\omega_2)(\omega_3)(\omega_4)$$

$$R_{f1} = (0.025)(0.05)(0.04)(0.05)(0.25) = 0.62 \times 10^{-6}$$

$$D_i = R_{f1} \times D_0 = 0.62 \times 10^{-6} \times 0.93 \times 10^5$$

$$\tilde{=} 0.1 \text{ rads at Point 4}$$

9) Residual Contribution through Roof Slabs and Walls of Entrance Structure.

(a) Slab at Point 1.

W = 4 ft., L = 4 ft., Z = 4 ft.

Therefore, e = 1 and n = 2

From Chart 3, Ref. 6.02, $\omega_o = 0.13$

From Chart 4, Ref. 6.02, $C_o(\omega_o, 180 \text{ psf}) = 0.0015$

$R_f = C_o(0.1\,\omega_2)(0.5\,\omega_3)(0.5\,\omega_4) = 2.20 \times 10^{-8}$

$D_i = R_f \times D_o = 2.20 \times 10^{-8} \times 0.93 \times 10^5$

= negligible dose at Point 4

(b) <u>Slab at Point 2.</u> (Fig. 9.10).

ω	W	L	Z	e	n	ω	X_o
ω_{o1}	4	4	4	1	2	0.13	560
ω_{o2}	4	7.67	6.83	0.522	1.78	0.09	370
ω_{o3}	4	12.67	6.83	0.315	1.09	0.13	180

$$C_o = C_{o1}(\omega_{o1}, X_{o1}) + \frac{1}{2}\left[C_{o2}(\omega_{o2}, X_{o2}) - C_{o1}(\omega_{o1}, X_{o2})\right]$$
$$+ \frac{1}{2}\left[C_{o3}(\omega_{o3}, X_{o3}) - C_{o2}(\omega_{o2}, X_{o3})\right]$$

From Chart 4, Ref. 6.02,

$\qquad C_{o1}(\omega_{o1}, X_{o1}) = \ll 0.0001$

$\qquad C_{o1}(\omega_{o1}, X_{o2}) = < 0.0001$

$\qquad C_{o2}(\omega_{o2}, X_{o2}) = < 0.0001$

$\qquad C_{o2}(\omega_{o2}, X_{o3}) = 0.0009$

$\qquad C_{o3}(\omega_{o3}, X_{o3}) = 0.0014$

$C_o = \ll 0.0001 + \frac{1}{2}\ (< 0.0001 - < 0.0001)$

$\qquad + \frac{1}{2}\ (0.0014 - 0.0009) = 0.00025$

Therefore, $R_f = C_o(0.1\,\omega_3)(0.5\,\omega_4) = 1.81 \times 10^{-7}$

$D_i = R_f \times D_o = 1.81 \times 10^{-7} \times 0.93 \times 10^5$

= negligible dose at Point 4

(c) <u>Slab at Point 3</u>. Even if ω_o were 1.0, (i.e., effect
of geometry neglected) the contribution $C_o(1.0, 560 \text{ psf})$
is $\ll 0.0001$. (Chart 4, Ref. 6.02).
Therefore, $R_f = C_o(0.1 \, \omega_4) = \ll 10^{-4} \times 0.1 \times 0.29$
$$= \ll 2.9 \times 10^{-6}$$
Therefore, $D_i = R_f \times D_o = \ll 2.9 \times 10^{-6} \times 0.93 \times 10^5$,
$$= \ll 0.27 \text{ rads dose at Point 4}$$

10) <u>Total Prompt plus Residual Radiation Dose</u>. The radiation
doses at Point 4 calculated in the previous paragraphs are summarized as
follows:

Source of Dose	Prompt Neutron	Prompt Gamma	Residual Gamma
Entrance Opening	3.5 - 1)*	0.1 - 4)	0.1 - 8)(f)
Roof Slab - Point 1	1.2 - 2)(a)(3)	negl. - 5)(a)	negl. - 9)(a)
Roof Slab - Point 2	negl. - 2)(b)(3)	negl. - 5)(b)	negl. - 9)(b)
Roof Slab - Point 3	-	negl. - 5)(c)	0.27 - 9)(c)
Walls	<u>negl. - 2)(c)</u>	<u>negl. - 5)(d)</u>	<u>-</u>
Total Doses	4.7 rads	0.1 rads	0.37 rads
Total Dose			5.2 rads

*Refers to section in which the dose was calculated.

If, as was assumed for this illustrative design example, a total
dose of 20 rads is permissible through the entranceway, then this entrance-
way design is more than adequate. It is worthwhile at this point to
examine the effect of omitting one or more legs of the entranceway corridor.
Only the effect of omitting the third and/or fourth legs will be examined,
inasmuch as the first two legs are required to descend to the assumed
level of the shelter, the Building Exits Code of the National Fire Code
limits the vertical distance between landings to $8'-6"$, and a turtuous
path is required to prevent the blast wave from reforming as an ideal shock.

Omission of the fourth leg of the corridor would increase the
prompt neutron dose just inside the shelter by a factor of approximately 2

to the $\frac{5}{4.03}$ power, or by a factor of 2.36. The prompt gamma and residual gamma dose would at the same time be increased by a factor of approximately

$$\frac{1}{0.5\ \omega_4} = \frac{1}{0.5 \times 0.29} = 6.9$$

Therefore, the total prompt plus residual dose received inside the shelter when the fourth leg and third bend are omitted is:

Prompt Neutron	2.36 x 4.7	=	11.1 rads
Prompt Gamma	6.9 x 0.1	=	0.7 rads
Residual Gamma	6.9 x 0.4	=	2.8 rads
	Total Dose		14.6 rads

Therefore, from the radiation shielding standpoint, the fourth leg and associated bend could be omitted and the shelter entered directly along an extension of the third leg provided the dimensions and orientation of the shelter proper were such that this entrance configuration would be possible.

Omission of the third and fourth leg and associated bends would increase the prompt neutron dose inside the shelter proper approximately by a factor of 2 to the $\frac{16}{4.03}$ power, or by a factor of 15.6. The prompt gamma and residual gamma dose would be increased by a factor of

$$\frac{1}{(0.5\ \omega_3)(0.5\ \omega_4)} = 276$$

Therefore, the total prompt plus residual dose received within the shelter proper when the third and fourth leg and associated bends are omitted would be:

Prompt Neutron	15.6 x 4.7	=	73 rads
Prompt Gamma	276 x 0.1	=	28 rads
Residual Gamma	276 x 0.4	=	110 rads
	Total Dose		211 rads

Therefore, from the radiation shielding standpoint, the third and fourth legs and associated bends can not be omitted unless a barrier is placed perpendicular to the last leg and within the shelter proper.

        In the design of an entranceway for an actual shelter,
additional possibilities should be investigated such as the inclusion
of a barrier, the reduction in length of the third leg and omission
of the fourth leg, etc. The most desirable solution would be that one
which provides the required protection at the least cost. Furthermore,
when the total shelter system, i.e., the entranceway and the shelter
proper, is being designed, a reapportioning of the amounts of radiation
allowed through the entranceway and shelter proper may be required in
order to obtain the most economic design for the total shelter system.

9.05 BLAST RESISTANT DESIGN

1) Pressures.

(a) Side-on Overpressure.

$$P_{so} = 50 \text{ psi}$$

(b) Peak Reflected Overpressure. At top (exterior
stairway, landing, and interior stairway) the
pressure is

$$P_r = 2 \, P_{so} \, \left(\frac{7P_o + 4P_{so}}{7P_o + P_{so}} \right) = 200 \text{ psi}$$

(c) Peak Reflected Overpressure. In corridor below
ground with tortuous entrance (2 - 90 degree bends)
the pressure is

$$P_r = 2 \, P_{so} = 100 \text{ psi}$$

2) Material Properties.

(a) Soil Properties. Stiff unsaturated clay, estimate

(1) $K_o = \frac{1}{2}$

(2) $k = 100$ psi per inch of deflection

(3) $\varphi = 0, \therefore K_p = 1$

(4) $\gamma = 120 \text{ lbs/ft.}^3 \sim 0.07 \text{ lbs/in}^3$

(5) $c = 1 \text{ ton/ft.}^2 \sim 14 \text{ psi}$

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    (b) <u>Structural Material Properties</u>.

        (1) <u>Concrete</u>. $f'_c = 3000$ psi

$$f'_{dc} = 1.25\ f'_c = 3750\ \text{psi}$$

$$u_d = 0.15\ f'_c = 450\ \text{psi}$$

$$E_c = 1000\ f'_c = 3 \times 10^6\ \text{psi}$$

$$n = E_s/E_c = 10$$

        (2) <u>Reinforcing Steel</u>. Intermediate grade with ASTM A-305 deformations

$$f_{dy} = 52,000\ \text{psi}$$

3) <u>Design of Walls Adjacent to Open Stairwell</u>.

    (a) <u>Lateral Loads on Wall</u>.

(1) <u>Inward Loading</u>   (2) <u>Outward Loading</u>
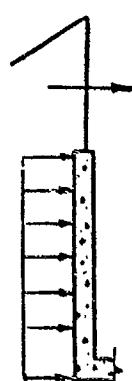
$p_r = 200$ psi

$p_h = K_o p_{so} = (\tfrac{1}{2})(50) = 25$ psi
uniformly distributed
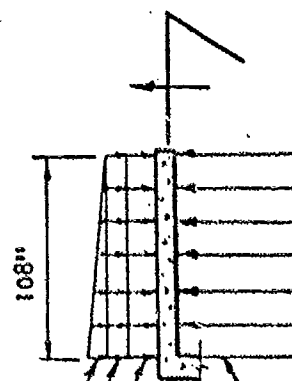
$K_p p_{so} = (1)(50) = 50$ psi

$2c\sqrt{K_p} = (2)(14\ \text{psi})(1) = 28$ psi

$\gamma z K_p = (.07\ \text{lb/in}^3)(108'')(1) = 8$ psi

Net $= 200-50-28-4 = 118$ psi
(controls design)

(b) <u>Analysis.</u> Use a triangular shape to approximate the
wall dimensions.
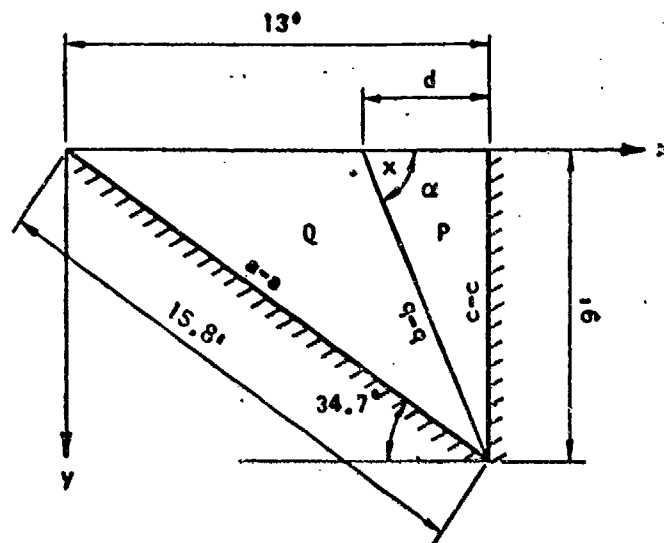
(1) <u>Assumptions.</u>

    a. Pilaster along c-c to provide fixity for slab.

    b. Yield moments along lines over supports a-a
       and c-c.

    c. Yield moment along line b-b at angle α
       with x-axis.

    d. Similar reinforcement in x and y directions;
       .˙. yield moments are equal, i.e., $m_x = m_y$
       where m_x and m_y are the yield moments in ft.lbs/ft.
       in the x and y directions respectively.

Note: Since yield line intersects free edge
at angle $\alpha \neq 90^{\circ}$, need a "substitute
corner shear" as in elasticity.

$m_t = m_y \cot \alpha =$ normal $\downarrow$ shear
$\qquad\qquad\qquad$ force in obtuse $\angle$ (·)
$\qquad\qquad$ = normal $\uparrow$ shear
$\qquad\qquad\qquad$ force in acute $\angle$ (x)

$m_t = \left(\dfrac{d}{9}\right) m_y$

(2) <u>Wall Portion P.</u>

Moment about c-c of yield moment acting
along b-b

$= (m_y)(\text{length b-b})(\sin \alpha)$

$= (m_y)\left(\dfrac{9}{\sin \alpha}\right)(\sin \alpha) = 9\, m_y$

$\Sigma\, M_{c-c} = 9\, m_c + 9\, m_y - m_y\left(\dfrac{d}{9}\right) d - \dfrac{w_p(9)\,d}{2}\dfrac{d}{3} = 0$

$\qquad\quad = 9\, m_y + 9\, m_y - \dfrac{d^2}{9} m_y - \dfrac{3d^2}{2}\, w_p = 0$

$w_p = \left(\dfrac{2}{3d^2}\right)(m_y)\left(18 - \dfrac{d^2}{9}\right) = m_y\left(\dfrac{12}{d^2} - 0.074\right)$

where m_y, ft.lb/ft.
$\qquad$ d, ft.
$\qquad$ w_p, lb/ft.^{2}
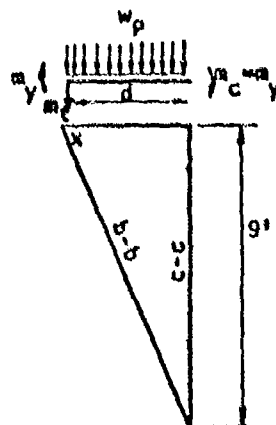
(3)   Wall Portion Q.
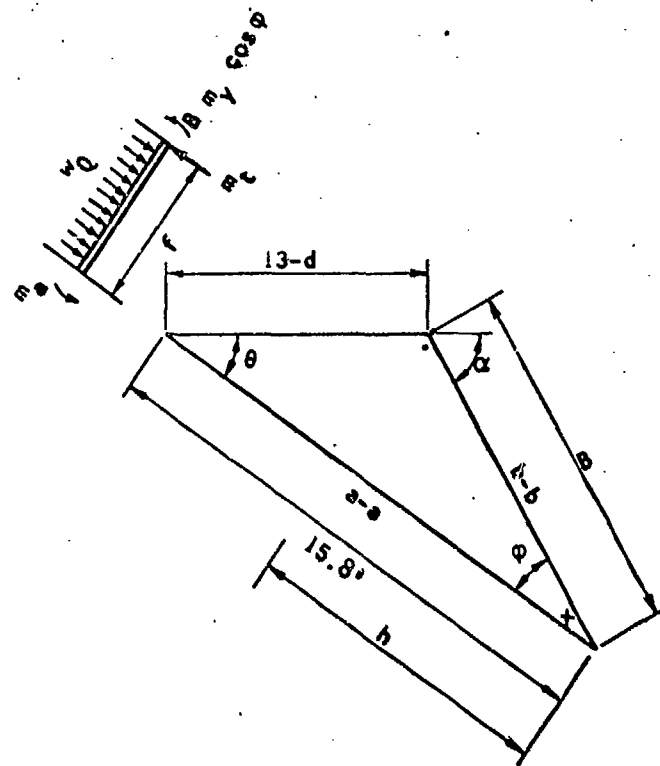
$$\varphi = \alpha - 34.7^\circ$$
$$h = B \cos \varphi$$
$$f = B \sin \varphi$$
$$m_t = \frac{d}{9} m_y$$

Moment about a-a of yield moment along b-b $= B\, m_y \cos \varphi$

Substitute corner shear is $m_t = \frac{d}{9} m_y$

When $m_x = m_y$, yield moment along a line at angle θ is

$$m_\theta = m_x \cos^2 \theta + m_y \sin^2 \theta = m_y; \ \therefore \ m_a = m_\theta = m_y$$

$$\Sigma M_{a-a} = 15.8\, m_a + B\, m_y \cos \varphi + m_t\, f - \frac{w_Q(15.8)f}{2}\,\frac{f}{3} = 0$$

$$= 15.8\, m_a + B\, m_y \cos \varphi + \frac{df}{9} m_y - 2.63\, f^2 w_Q = 0$$

$$w_Q = \frac{1}{2.63\, f^2} \left\{ m_y \left(15.8 + B \cos \varphi + \frac{df}{9}\right) \right\}$$

(4) <u>Equate w_P and w_Q.</u> To obtain uniform load giving
yield moments indicated in portions P and Q, equate
w_P and w_Q:

$$\left(\frac{12}{d^2} - 0.074\right) = \frac{1}{2.63\ f^2}\left(15.8 + h + \frac{df}{9}\right).$$

By Trial and Error solve this equation.

Try d = 4.7 ft., $\tan \alpha = \frac{9.0}{4.7} = 1.915$, $\alpha = 62.4^\circ$

$\varphi = 27.7^\circ$, $\sin \varphi = 0.464$, $\cos \varphi = 0.886$

$B = \frac{9}{\sin \alpha} = \frac{9}{0.886} = 10.17$ ft.

$f = B \sin \varphi = 4.72$ ft.

$h = B \cos \varphi = 9.00$ ft.

$w_P = m_y\left[\frac{12}{(4.7)^2} - 0.074\right] = m_y\ (0.544 - 0.074) = 0.470\ m_y$

$w_Q = \frac{m_y}{(2.63)(4.72)^2}\left[15.8 + 9.00 + \frac{(4.7)(4.72)}{9.0}\right]$

$= 0.467\ m_y$ (close enough to $0.470\ m_y$)

where w is in lbs/ft.$^2 \sim .470\ m_y$

(c) <u>Required Flexural Section.</u>

(1) <u>Resistance.</u>

Now $\frac{p_m}{q_y} = 1 - \frac{1}{2\mu}$, where $\mu = 3$

$p_m = 0.833\ q_y$ where p_m & q_y are in psi

For $p_m = 25$ psi, $q_y = 30$ psi

For $p_m = 116$ psi, $q_y = 141$ psi

(2) <u>Section</u>.

But from above $\frac{w}{144} = q_y = \frac{0.470}{144} m_y = 0.00326 m_y$

Now $m_y = 0.009 \, \varphi \, f_{dy} \, a \, d^2$, if $\varphi \sim 0.5\%$

$\quad m_y = (0.009)(0.5)(52000)(1 \text{ ft}) d^2$
$\quad\quad = 234 \, d^2 \text{ ft.lb/ft.}$

For $q_y = 30$ psi, $d^2 = \frac{30}{(0.00326)(234)} = 40$

Therefore, $d \sim 6\frac{1}{2}$ in., say 7 in.

$\quad$ For $\varphi = 0.5$, $A_s = (0.005)(7)(12)$

$\quad\quad = 0.42$ sq.in/ft.

$\quad$ Use #5 at 8 in., $(0.31)(\frac{3}{2}) = 0.46$ sq.in/ft.

$\quad\quad$ (each way, each face)

$\quad\quad \varphi = \varphi' = 0.55\%$

$\quad$ Anchorage required, Length $= \frac{f_{dy}}{4u} D$

$\quad\quad\quad = \frac{52000}{4 \times 450} \times \frac{5}{8} = 18$ in.

For $q_y = 141$ psi

$\quad d^2 = \frac{141}{(0.00326)(234)} = 186$, $d \sim 13\frac{1}{2}$ in., say 14 in.

Thickness $= 17$ in.

For $\varphi = 0.5$, $A_s = (0.005)(14)(12) = 0.84$ sq.in/ft.

$\quad$ Use #7 at 8 in., $(0.60)(\frac{3}{2}) = 0.90$ sq.in/ft.

$\quad\quad$ (each way, each face)

$\quad\quad \varphi = \varphi' = 0.54\%$

$\quad$ Anchorage required, Length $= \frac{52000}{4 \times 450} \times \frac{7}{8} = 25$ in.

(d) <u>Diagonal Tension and Shear</u>. Previous calculations are
for ductile behavior in flexure. Yield resistance in
shear and diagonal tension must exceed flexural
resistance. For diagonal tension and pure shear idealize
by considering a one-way slab with fixed supports at
mid-depth (L = 78 in.).

(1) <u>Diagonal Tension</u>.

Take #6 at 6 in. horizontally (slightly < d/2)

at 8 in. vertically (= spacing of flexural
reinforcement)

$$\varphi_v = \frac{0.44}{8 \times 6} = 0.92$$

$$q_y = 100 \left(\frac{1}{3} + \frac{1}{2} \frac{\varphi'}{\varphi}\right) \left(1 + \frac{2\varphi_v f_{dy}}{10^5}\right) \sqrt{\varphi f_c'} \; \left(\frac{d}{L}\right)^2$$

$$= 100 \left(\frac{1}{3} + \frac{1}{2} \frac{0.54}{0.54}\right) \left[1 + \frac{2 \, (0.92)(52000)}{10^5}\right]$$

$$x \sqrt{(0.54)(3000)} \left[\frac{14}{(6.5)(12)}\right]^2$$

$$= 100 \; (0.833)(1 + 0.96)(40.3)(0.18)^2$$

$$= (6580)(0.0324) = 213 \text{ psi} > 141 \text{ psi, OK}$$

(2) <u>Pure Shear</u>.

For $\frac{d}{L} < 0.2$, $q_y = 0.44 \; f_c' \frac{d/L}{1 - d/L}$

at mid height, $\frac{d}{L} = 0.18$, $q_y = (0.44)(3000)\left(\frac{0.18}{0.82}\right)$

$$= 290 \text{ psi} > 141 \text{ psi}$$

at top, $\frac{d}{L} = 0.09$, $q_y = (0.44)(3000)\left(\frac{0.09}{0.91}\right)$

$$= 131 \text{ psi, say OK}$$

(e) <u>Sketch</u>. Fig. 9.11 is a sketch of the reinforcement
in the exterior stairway walls.

4) <u>Stairway Slab</u>. The wall design was based on the assumption
that a yield moment existed along line a-a, i.e., at the stairway slab.
The yield moment of the stairway slab must be at least equal to the yield
moment of the wall in order to provide continuity at the corner. Therefore,
the minimum slab section must correspond to the wall section, i.e., d = 14"
with #7 at 8 in. in each face. This requirement is greater than that for
the interior stair floor section which carries a similar loading; see
paragraph 9.05-5).

Therefore use $d = 14$ in.

$t = 18$ in. (4 in. cover to ctr. bottom steel)

#7 at 8 in. top and bottom

5) Design of Corridor Section.

Interior dimensions: width $= 48$ inches

height $= 84$ inches

(a) Wall Section.

(1) Loadings.

Design as one-way slab with fixed supports.

Load acting inward:

$p_m = K_o p_{so} = 25$ psi

Using $\mu = 3$, required $q_y = \dfrac{p_m}{1 - \dfrac{1}{2\mu}} = 30$ psi

Proportion wall section for this load and check
for condition with following load acting outward:

$p_r = 100$ psi with $\mu = 10$

(2) Design.

Assume thickness $= 10$ in.

$d = 7.5$ in. (2.5 in. cover
to ctr. steel)

$L = 84$ in., $\dfrac{d}{L} = 0.089$

a. Flexure.

$q_y = 0.072 \ (\varphi + \varphi') \ f_{dy} \ \left(\dfrac{d}{L}\right)^2$

Therefore $(\varphi + \varphi') = \dfrac{30}{(0.072)(52000)(0.089)^2}$

$= 1.01\%$

For $\varphi = \varphi' = 0.50\%$, $A_s = 0.0050 \times 7.5 \times 12$
$= 0.45$ in.^{2}/ft.

Use #5 at 8 in., $A_s = 0.47$ in.^{2}/ft. each face
$\varphi = \varphi' = 0.52\%$

$q_y = 0.072 \ (0.52 + 0.52)(52000)(0.089)^2$
$= 30.9$ psi > 30 psi, OK

b. <u>Diagonal Tension and Shear</u>. To assure ductile behavior, the yield resistances for diagonal tension and pure shear must exceed 30.9 psi, i.e., the flexural yield resistance.

<u>Diagonal Tension</u>

Assume minimum percentage of shear reinforcement:

$\varphi_v = 0.25\%$

Try #3 at 4 in. vertically (approximately d/2)
       at 8 in. horizontally (= spacing
          of vertical reinforcement)

$$\varphi_v = \frac{0.11}{8 \times 4} = 0.34\%$$

$$q_y = 100 \left[\frac{1}{3} + \frac{1}{2}\frac{\varphi'}{\varphi}\right]\left[1 + \frac{2\,\varphi_u\,f_{dy}}{10^5}\right]\sqrt{\varphi\,f'_c}\,\left(\frac{d}{L}\right)^2$$

$$q_y = 100 \left[\frac{1}{3} \times \frac{1}{2}\frac{0.52}{0.52}\right]\left[1 + \frac{2 \times 0.34 \times 52000}{10^5}\right]$$

$$\sqrt{0.52 \times 3000}\,(0.089)^2$$

$$= 35.3 \text{ psi} > 30.9 \text{ psi}$$

Therefore, the assumed dimensions are satisfactory subject to further check.

<u>Pure Shear</u>

For $\frac{d}{L} < 0.2$, $q_y = 0.44\,f'_c\,\dfrac{\frac{d}{L}}{1 - \frac{d}{L}}$

Therefore, $q_y = 0.44 \times 3000 \times \dfrac{0.089}{1-0.089}$

$$= 129 \text{ psi} > 30.9 \text{ psi, OK}$$

c. <u>Yield Deflection</u>

$$k' = \sqrt{\frac{\varphi n}{50} + \left(\frac{\varphi n}{100}\right)^2} - \frac{\varphi n}{100}$$

$$= \sqrt{\frac{0.52 \times 10}{50} + \left(\frac{0.52 \times 10}{100}\right)^2} - \frac{0.52 \times 10}{100}$$

$$= 0.327 - 0.052 = 0.275$$

$$I = \frac{(k'd)^3}{3} + \frac{n\,\varphi\,d^3}{100}\,(1 - k')^2$$

$$= \frac{(0.275 \times 7.5)^3}{3} + \frac{10 \times 0.52 \times 7.5^3}{100}(1-0.275)^2$$

$$= 2.9 + 11.5 = 14.4 \text{ in}^4$$

Therefore, $x_y = \dfrac{q_y l^4}{307\,E_c\,I}$

$$= \frac{30.9 \times (84)^4}{307 \times 3 \times 10^6 \times 14.4} = 0.12 \text{ in.}$$

d. <u>Ultimate Deflection for Load Acting Outward,</u>
   <u>$p_r = 100$ psi</u>

Using $\mu = 10$, $x_u = 10\,x_y = 10 \times 0.12 = 1.2$ in.

Maximum passive resistance available > 80 psi
        (see paragraph 3)

Required passive resistance $= 100 - 30.9$

$\qquad = 69.1 < 80$, OK

Passive resistance mobilized $= K_o p_{so} + k\,x_u$

Therefore, $x_u = \dfrac{69.1 - K_o p_{so}}{K} = \dfrac{69.1 - 25}{100}$

$\qquad = 0.44$ in. < 1.2 in., OK

Since the required passive resistance is less
than the maximum which can be developed, and
the required ultimate deflection to mobilize
this is less than the $10\,x_y$, the load acting
inward controls the design.

(b) <u>Roof and Floor Section.</u>

   (1) <u>Loadings.</u>

      Design as one-way slab with fixed supports.
Load acting inward (neglecting weight of soil
and concrete which are small compared with
pressures acting): $p_m = p_{so} = 50$ psi

      Load acting outward: $p_m = p_r - p_{so} = 100-50 = 50$ psi

      Proportion roof and floor sections for 50 psi
acting in either direction.

      Using $\mu = 3$, required $q_y = \dfrac{p_m}{1 - \dfrac{1}{2\mu}} = 60$ psi

   (2) <u>Design.</u>

      Assume thickness = 10 in. (same as walls)

$$d = 7.5 \text{ in.}$$

      $L = 48$ in., $d/L = 0.156$

      a. <u>Flexure</u>

         In order to satisfy the assumption of fixed
ends for the wall section, the minimum
reinforcement in the roof and floor must
correspond to that selected for the walls.
Therefore, try #5 at 8 in. each face,

         $\varphi = \varphi' = 0.52\%$

         $q_y = 0.072 \, (0.52 + 0.52)(52000)(0.156)^2$

           $= 94.5 > 60$ psi, OK

         Use #5 at 8 in. each face

      b. <u>Diagonal Tension</u>

         Use same shear reinforcement as in walls,

         $\varphi_u = 0.34\%$

$$q_y = 100 \left[\frac{1}{3} + \frac{1}{2}\frac{0.52}{0.52}\right]\left[1 + \frac{2 \times 0.34 \times 52000}{10^5}\right]$$

$$\times \sqrt{0.52 \times 3000} \ (0.156)^2$$

$$= 108.5 \text{ psi} > 94.5 \text{ psi, OK}$$

c. **Pure Shear**

For $\frac{d}{L} < 0.2$, $q_y = 0.44 \times 3000 \frac{0.156}{1-0.156}$

$$= 244 \text{ psi} > 94.5 \text{ psi, OK}$$

(c) **Anchorage Requirements.**

Required length of anchorage $= \frac{f_{dy}}{4 u_d}$ (bar diameter)

For #5 bars: $\frac{52000}{4 \times 450} \times \frac{5}{8} = 18$ in.

(d) **Longitudinal Reinforcement.**

Use 0.25%, $A_s = 0.25 \times 10 \times 12 = 0.30$ in.^{2}/ft.

Use #4 at 16 in. each face

(e) **Sketch.** Fig. 9.12 is a sketch of the reinforcement in the corridor section.

6) **Design of Interior Stair Section.**

Interior dimensions: width   =   48 inches

                   height =   106 inches vertical

                        =   82 inches normal to stairs

(a) **Wall Section.**

(1) **Loadings.**

Design as one-way slab with fixed supports.

Load acting inward: $p_m = K_o p_{so} = 25$ psi

Using $u = 3$, required $q_y = 30$ psi

Load acting outward: $p_r = 200$ psi with $\mu = 10$

The maximum passive resistance available to a
depth of 9 ft. is 82 psi, see paragraph 3).
Thus, the passive resistance expressed as a
function of the subgrade modulus, $K_o p_{so} + k x_u$,
should not exceed 82 psi. The minimum
deflection which will mobilize this resistance
is therefore:

$$K_o p_{so} + k x_u = 82$$

$$\frac{1}{2}(50) + 100\, x_u = 82$$

$$x_u = \frac{82 - 25}{100} = 0.57 \text{ in.}$$

The corresponding yield deflection is $x_y = x_u/10$
= 0.057 in.

The design of the walls will be made on the
assumption that the full passive resistance is
mobilized, i.e., $q_y = 200 - 82 = 118$ psi. The
yield deflection will then be checked and
compared with the minimum yield resistance of
0.057 in.

(2) Design.

Use $q_y = 118$ psi

Assume thickness = 14 in.

$$d = 11.5 \text{ in.}$$

$L = 82$ in., $d/L = 0.140$

a. Flexure

$$\varphi + \varphi' = \frac{118}{0.072(52000)(0.140)^2} = 1.61\%$$

For $\varphi = \varphi' = 0.805\%$, $A_s = 0.0805 \times 11.5 \times 12$

= 1.11 in^2/ft. inclined

Required vertical $A_s = 1.11 \left(\frac{106}{82}\right)^2 = 1.86$ in^2/ft.

Use #8 at 5 in., $A_s = 1.90$ in^2/ft. each

face vertical

inclined $A_s = 1.14$ in^2/ft.

$\varphi = \varphi' = 0.82\%$

$q_y = 0.072(0.82 + 0.82)(52000)(0.140)^2$

$= 120$ psi > 118 psi, OK

b. Yield Deflection

$k' = \sqrt{\dfrac{0.82 \times 10}{50} + (\dfrac{0.82 \times 10}{100})^2} - \dfrac{0.82 \times 10}{100}$

$= 0.315$

$I = \dfrac{(0.315 \times 11.5)^3}{3} + \dfrac{10 \times 0.82 \times 11.5^3}{100} \times$

$(1 - 0.315)^2 = 15.9 + 58.5 = 74.4$ in^4

$\dot{y} = \dfrac{120 \times 82^4}{307 \times 3 \times 10^6 \times 74.4}$

$= 0.0792$ in. > 0.057 in., OK

c. Diagonal Tension

Try #3 stirrups at 5 in. vertically

at 5 in. horizontally

$\varphi_v = \dfrac{0.11}{5 \times 5} = 0.44\%$

$q_y = 100\left[\dfrac{1}{3} + \dfrac{1}{2}\dfrac{0.82}{0.82}\right]\left[1 + \dfrac{2 \times 0.44 \times 52000}{10^5}\right]$

$\times \sqrt{0.82 \times 3000 (0.140)^2}$

$= 118$ psi ~ 120 psi, OK

d. Pure Shear

For $\dfrac{d}{L} < 0.2$, $q_y = 0.44 \times 3000 \times \dfrac{0.140}{(1 - 0.140)}$

$= 215$ psi > 120 psi, OK

Since the section is satisfactory for diagonal
tension and pure shear the reinforcement
selected on the basis of flexure is satisfactory.

(b) Roof and Floor Section.

  (1) Loadings.

     Design as one-way slab with fixed supports.
     Load acting inward (neglecting weight of soil
     and concrete): $P_m = P_{so} = 50$ psi.

     Load acting outward: $P_m = P_r - P_{so} = 200-50 = 150$ psi

     Proportion roof and floor sections for 150 psi
     acting outward.

     Using $\mu = 3$, required $q_y = \dfrac{P_m}{1 - \dfrac{1}{2\mu}} = 180$ psi

  (2) Design.

     Assume thickness = 12 in.

                   d = 9.5 in.

     L = 48 in., d/L = 0.198

     a. Flexure

$$\varphi + \varphi' = \frac{180}{0.072\ (52000)(0.198)^2} = 1.23\%$$

        For $\varphi = \varphi' = 0.62\%$, $A_s = 0.0062 \times 9.5 \times 12$

            = 0.71 in^2/ft. required

        Available from wall reinforcement: #8 at $6\frac{1}{2}$ in.,
        Therefore, $A_s = 1.46$ in^2/ft. each face

        $\varphi = \varphi' = 1.28$

        $q_y = 0.072\ (1.28 + 1.28)(52000)(0.198)^2$

           = 376 psi > 180 psi, OK

     b. Diagonal Tension

        Try #3 stirrups at 4 in. longitudinally in span
                        at $6\frac{1}{2}$ in. transversely in span

        $\varphi_u = \dfrac{0.11}{4 \times 6.5} = 0.424$

$$q_y = 100\left[\frac{1}{3} + \frac{1}{2}\,\frac{1.28}{1.28}\right]\left[1 + \frac{2 \times 0.424 \times 52000}{10^5}\right]$$

$$\sqrt{1.28 \times 3000}\ (0.198)^2$$

= 291 psi < 376 psi, but ≫ 180 psi, therefore, OK

(c) Pure Shear

For $\frac{d}{L} < 0.2$, $q_y = 0.44 \times 3000\,\frac{0.198}{1 - 0.198}$

= 326 psi < 376 psi, but ≫ 180 psi, therefore, OK

Therefore, the dimensions and reinforcement selected are satisfactory.

(c) Anchorage Requirements.

For #8 bars: $\frac{52000}{4 \times 450} \times \frac{8}{8} = 29$ in.

(d) Longitudinal Reinforcement.

Same as for corridor section, #4 at 16 in. each face.

(e) Sketch. Fig. 9.13 is a sketch of the reinforcement in the interior stair section.

7) Design of Landing.

Interior dimensions: height = 96 inches

width = see plan
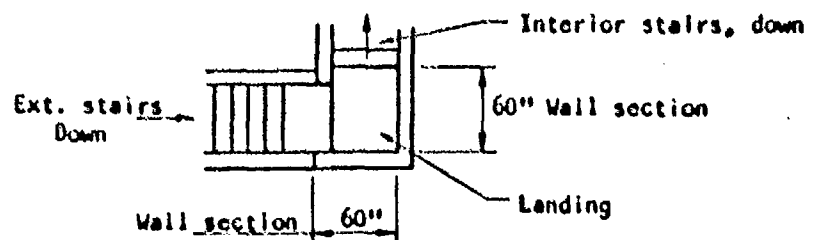
(a) <u>Wall Section.</u>

    (1) <u>Loadings.</u>

        Load acting inward: $p_m = K_o p_{so} = 25$ psi

        Using $\mu = 3$, required $q_y = 30$ psi

        Load acting outward: $p_r = 200$ psi

    (2) <u>Design.</u>

        Design as two-way slab fixed at roof and floor
        and at the corner:
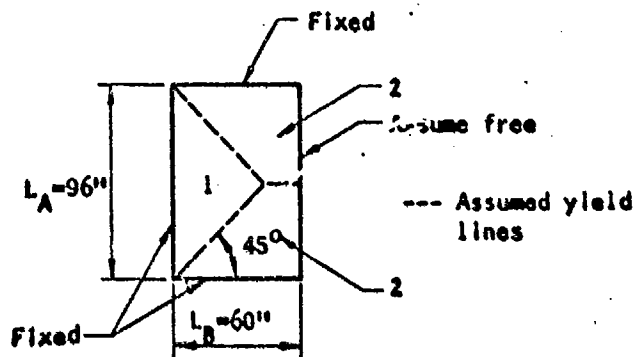
An approximate yield line analysis will be made.
Yield lines are assumed as shown. Since the
yield line locations have been assumed, the yield
resistances for areas (1) and (2) will not in
general be equal as would be the case if the
yield lines were in their theoretically correct
position. If the arbitrary yield line location
is reasonable, however, the yield resistance of
the slab may be taken as the weighted average
of the resistances of the individual areas, i.e.,

$$q_y = \frac{q_1 A_1 + q_2 A_2}{A_1 + A_2}$$

where q is the yield resistance and A the area
of the individual areas indicated by the sub-
script. The yield resistance for the slab on

this basis becomes, for $\frac{L_A}{L_B} \leq 2$:

$$q_y = \frac{1}{L_A L_B}\left[6(M_B^+ + M_B^-) + 8(M_A^+ + M_A^-)\frac{L_B}{L_A}\frac{(1 - \frac{L_A}{4 L_B})}{(1 - \frac{L_A}{3 L_B})}\right]$$

where L is the span and M the corresponding positive or negative resisting moment, subscripts A and B referring to the long and short spans, respectively.

The walls for the adjacent interior stairway were designed using $q_y = 118$ psi acting outward. If the same wall thickness is used here, the deflections will be similar and the passive soil resistance will also be similar. Therefore, design for $q_y = 118$ psi.

Use: thickness = 14 in.

   d = 11.0 in. (average d for 2 layers of steel)

$L_A = 96$ in.

$L_B = 60$ in.

a.   Flexure

$$q_y = \frac{1}{L_A L_B}\left[6(M_B^+ + M_B^-) + 8(M_A^+ + M_A^-)\frac{L_B}{L_A}\frac{(1 - \frac{L_A}{4 L_B})}{(1 - \frac{L_A}{3 L_B})}\right]$$

Make $M_A^+ = M_A^- = M_B^+ = M_B^- = M$, then

$$118 = \frac{1}{96 \times 60}\left[12 M + 16 M \frac{60}{96}\frac{(1 - \frac{96}{4 \times 60})}{(1 - \frac{96}{3 \times 60})}\right]$$

$$= \frac{1}{96 \times 60}\left[12 M + 12.9 M\right]$$

$$M = \frac{118 \times 96 \times 60}{24.9} = 27300 \text{ in.lb.} = 0.009 \, \varphi \, f_{dy} d^2$$

Therefore, $\varphi = \dfrac{27300}{0.009 \times 52000 \times 11^2} = 0.483\%$

$A_s = 0.00483 \times 11 \times 12 = 0.64 \text{ in}^2/\text{ft.}$
     horizontal and vertical, each face

Use #5 at 6 in. horizontal and vertical, each face.

$A_s = 0.66 \text{ in}^2/\text{ft.}$

b. Diagonal Tension and Pure Shear
    These requirements will be satisfied as for
    the interior stair walls since the length
    of support is greater (3 sides fixed) and
    the corresponding shears will be smaller.
    Use #3 stirrups at 6 in. vertically and
                                    6 in. horizontally.

(b) Roof and Floor.

    (1) Loadings.
         Load acting inward (neglecting weight of soil
         and slab): $p_m = p_{so} = 50$ psi

         Load acting outward: $p_m = p_r - p_{so} = 200 - 50 = 150$ psi

         Using $\mu = 3$, required $q_y = \dfrac{p_m}{1 - \dfrac{1}{2\mu}} = 180$ psi

    (2) Design. Design as two-way slab fixed on two
         adjacent sides with support at corner:

Support
Free
L_A
$L_A = 60"$
Yield lines
L_B $L_B = 60"$
Fixed at Walls
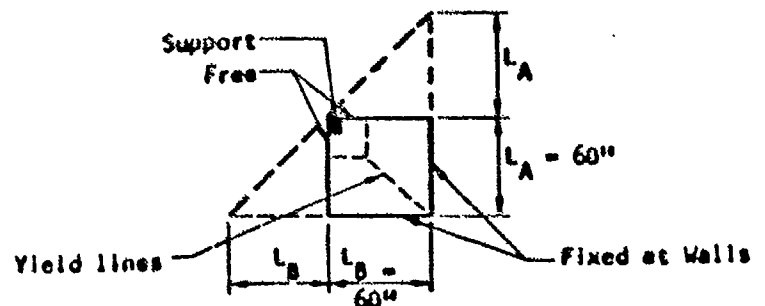
An approximate yield line analysis will be made.
Yield lines are assumed as shown intersecting
at the median of the triangle formed by extend-
ing the fixed sides to twice their length. The
yield resistance of the slab expressed as the
weighted average of the yield resistances of
the individual areas is

$$q_y = 4.6 \frac{M_A^+}{L_A^2} + 3.6 \frac{M_A^-}{L_A^2} + 4.6 \frac{M_B^+}{L_B^2} + 3.6 \frac{M_B^-}{L_B^2}$$

a. Flexure

$L_A = L_B = 60$ in.

Make $M_A^+ = M_A^- = M_B^+ = M_B^- = M$, then

$$180 = (4.6 + 3.6 + 4.6 + 3.6) \frac{M}{60^2}$$

$$M = \frac{180 \times 60^2}{16.4} = 39,400 \text{ in.lb.}$$

Use thickness = 14 in.

d = 11 in. (average for 2
layers of steel)

$$\varphi = \frac{M}{0.009 \, f_{dy} \, d^2} = \frac{39,400}{0.009 \times 52000 \times 11^2} = 0.70\%$$

$A_s = 0.0070 \times 11 \times 12 = 0.92$ in^2/ft. each
way in each face.

Use #7 at 6 in. each way in each face.

$A_s = 1.20$ in^2/f...

b. Diagonal Tension and Pure Shear

These requirements will be satisfied as for
the interior stairway roof since the landing
roof is thicker (14 in. versus 12 in.) and

the length of support is somewhat
greater (2 sides fixed plus about 24 In.
at corner support). Thus, the correspond-
ing shears will be smaller.

Use #4 stirrups at 6 in., each way

(c) Sketch. Fig. 9.14 is a sketch of the reinforcement
In the landing section. .

9.06 BLAST RESISTANT DESIGN (CHARTS)

In many cases the design of structural elements of the entrance-
way structure may be done more expeditiously by the use of the Design
Charts and Tables of Chapter 7.

Although it has been assumed for the purposes of this
Illustrative design example that there Is no requirement for an interlock
and the blast design of the structural elements and the radiation shield-
Ing analysis of the configuration has been performed accordingly, for
purposes of Illustration both an exterior door at the ground surface and
an interior door In the corridor will be designed In this section using
these Design Charts and Tables.

1) Horizontal Sliding Door at Ground Surface. The exterior
door at the ground surface is flush with the ground (0° angle of Incidence)
and is therefore designed for 50 psi side-on (Fig. 5.09). The door
opening Is 4 ft. by 12 ft. 9 In.. This latter dimension does not Influence
the structural design of the door.

(a) Door Design.

Assume: Effective Span = 48 In.

Chart 7.01 indicates that a thickness of flat
steel plate 1.25 In. thick will suffice,
weighing 50 lbs. per sq. ft.

Chart 7.07 Indicates a section modulus, Z/b, of
0.36 in.^{2} Is required.

Reference to the Design Tables of Chapter 7 will permit the
designer to choose the appropriate section. The following configurations

are adequate:

1. Rolled I-sections welded flange to flange (Table 7.05). Lightest possible section is 6B8.5 which provides a section modulus of 1.45 and weighs 25.9 lbs. per sq. ft.

2. Structural Tubing (Table 7.06). 2 x 2 x 0.154 provides a section modulus of 0.394 and weighs 21.9 lbs. per sq. ft.

3. Plate and beam section. No tables are provided for direct selection of plate and beam combinations. Building one up with plate of 0.25 in. thickness, Chart 7.02 indicates a maximum distance of 14 in. between line supports. Assume this to be center to center of beams, i.e., neglect the support provided by the beam flanges, and assume the beams to be 8 Jr 6.5. The following calculations are required:

$$S = \frac{I}{C} = 4.7 \text{ in}^3 \qquad \& \quad A = 1.92 \text{ in}^2$$

$$\frac{I}{b} = \frac{S \times \text{Shape Factor}}{\text{beam spacing}} = \frac{4.7 \times 1.0}{14} = 0.335 \text{ in}^2 < 0.36 \text{ in}^2$$

But would be adequate considering the contribution of the plate.

Shear Resistance Check.

Web Thickness = 0.135

Shear Resistance per beam = t_w x depth x 25,000

$$= 0.135 \times 8.0 \times 25,000$$
$$= 27,000 \text{ lbs.}$$

$$q_y \text{ (shear)} = \frac{27,000}{\text{spacing} \times \frac{1}{2} \text{ span}}$$

$$= \frac{27,000}{14 \times 24} = 81 \text{ psi}$$

<u>Flexural Resistance.</u>

For stability, limit contributing length of

$\frac{1}{4}$-in. plate so $\frac{b}{t_f} \leq 17$.

Therefore, $b = 17 \times 0.25 = 4.25$ in., and

Effective plate width $= 4.25 + 2.25 = 6.50$ in.

Combined area $= (6.50)(0.25) + 1.92 = 3.54$ in.^{2}

Therefore, N.A. occurs at depth where 1.77 in.^{2}

above and below:

$$\bar{x} = \frac{1.77 - 1.62}{2.281} = 0.066 \text{ in.}$$

Assume N.A. at plate-beam interface

Therefore, $M_u = \left[(1.62 \times \frac{1}{8}) + (1.92 \times 4) \right] 42,000$

$\qquad = 323,000$ in.lb.

$M_u = \frac{1}{8} q_y L^2 \times b$

$q_y = \frac{8 \times 323,000}{14 \times 48 \times 48} = 80$ psi

Therefore, section is adequate

(b) <u>Door Track.</u> The track for door to run in is to be
provided by a wide flange section cast into the side wall of entranceway.
For active pressure there is no problem since load acts down through the
wall and this is adequate.

For rebound we must check flange of section used.

Try 10WF33

Passive pressure $= \frac{1}{2} p_{so}$ (for rebound)

Therefore, load per inch of beam $= \frac{1}{2} \times 50 \times 24 = 600$ lb/in.

Moment at web fillet $= 600 \times 2$ in. $= 1,200$ in.lb/in.

$\frac{M_u}{f_{dy}} \qquad\qquad \frac{1,200}{42,000} = 0.0285$ in^3 required $\frac{Z}{b}$

$\frac{Z}{b}$ for 10WF33,

$\frac{bt^2}{4} = \frac{1 \times 0.433 \times 0.433}{4} = 0.047$ in^3 > 0.0285 in^3

Therefore, section adequate

(c) <u>Sketch</u>. Figs. 9.15 and 9.16 present details of the door and track design.

2) <u>Hinged Door in Corridor</u>. If an interlock element is desired an interior blast door must be placed in the entrance corridor near the shelter in order to protect those in the shelter in the event that the exterior door, e.g., at the ground surface, is not closed. The design provided in this example will consist of a swinging door opening outward into the entrance tunnel. The door is to be placed at some position along the final section of the corridor so that the support for the blast which the door must resist will be provided by the entrance corridor.

In order for the door to be out of the way of the flow of traffic it is necessary for the door to be recessed in the entrance corridor wall in a manner such as shown in Fig. 9.17.

Since it would be necessary to increase the roof span of the entrance corridor in this region, adequate resistance must be provided in this region. Procedures for this phase of the design are provided in other paragraphs of this chapter.

(a) <u>Door</u>.

Peak reflected pressure at door,

$p_r = 2 \ p_{so} = 2 \times 50 = 100$ psi

From Chart 7.07, the required $\frac{Z}{b} = 0.74$ in^3

From Table 7.06, this section modulus is provided by the following sections of hollow structural tubing connected to form a solid door.

$3\frac{1}{2} \times 3\frac{1}{2} \times 0.156$ 23.6 lb/ft.^{2} $\frac{Z}{b} = 0.75$

$4 \times 6 \times 0.188$ 23.8 lb/ft.^{2} $\frac{Z}{b} = 0.92$

(b) <u>Hinge</u>. For a 4 ft. by 7 ft. door the total weight will be approximately 720 lbs. including hardware. Since for this configuration the hinge is not called upon to resist any of the blast load, it must be designed to carry only the weight of the door.

The hinge should be provided with teflon sleeves and bearing surfaces so that corrosion will not be a problem and maintenance will be a minimum.

(c) _Sealing_. As mentioned previously the corridor wall provides support for the positive phase blast. Sealing can then be effected most conveniently by a passive gasket seal attached to the door or to the support surfaces.

(d) _Negative Phase or Rebound_. Resistance for this loading must be provided by some system inside the shelter area. The easiest way to provide this support is by a system of sliding bolts.

$$\text{Negative phase or rebound} = \frac{1}{2} P_r = 50 \text{ psi}$$

$$\text{Total load on door} = 48 \text{ in.} \times 84 \text{ in.} \times 50$$
$$= 189,000 \text{ lbs.}$$

The bolts provided should not undergo permanent deformation during this loading and should therefore be proportioned so that the maximum shear stress does not exceed 20,000 psi.

$$\text{Required bolt area} = \frac{189,000}{20,000} \approx 10 \text{ in.}^2$$

$$10 - 1\frac{1}{4} \varphi \text{ pins will be more than adequate}$$

These bolts (pins) must be supported and the load resisted transmitted to the door. In order to meet this requirement and to avoid local distress, an attachment is required on the inside face of the door. The thickness of this attachment must be checked to make sure that it is adequate in bearing.

$$0.6 f_y \frac{\pi d^2}{4} = 1.35 f_y t d$$

$$t = \frac{0.6}{1.35} \frac{\pi d}{4} = 0.35 d$$

For $d = 1.25$ in., $t = 0.44$ in.

Therefore, use ST 7 WF at 42

Web thickness ~ 0.451

The pins will slide into the wall and for this purpose a channel should be cast into the wall with holes drilled approximately 1/8 in.

oversize to accommodate the pins without difficulty.

Holes are also required in the ST 7 WF to accommodate the
pins. Slotted hollow tubes must be provided to keep the pins in position
for activation.

(e) <u>Sketch</u>. Fig. 9.18 is a cross-sectional view of the
door and its supports.

9.07 INTEGRATION OF STRUCTURAL ELEMENTS

As the designs in Sections 9.05 and 9.06 are presented solely
as an illustrative example, no attempt has been made to provide complete
structural details, nor to provide any uniformity of steel reinforcement.
These details, plus ties or dowels for continuity, must be considered
in the final design.
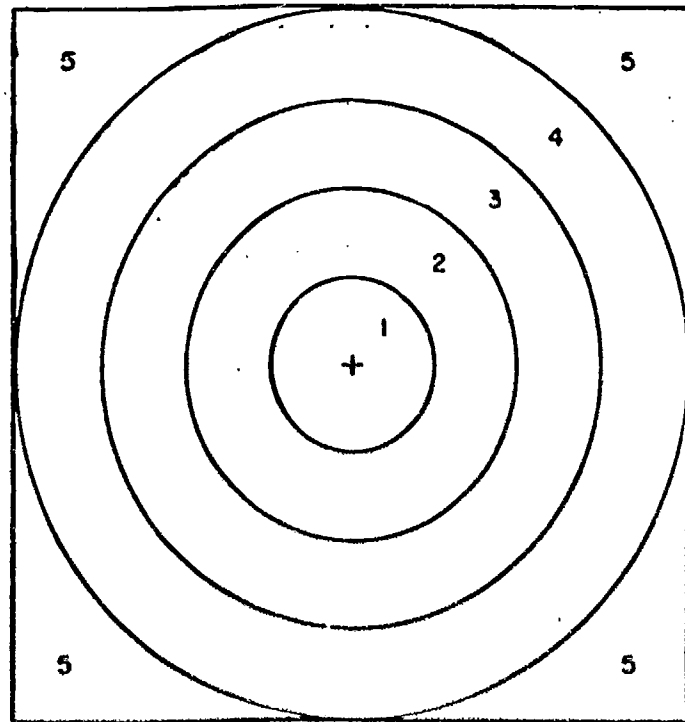
Limits Of Residential Area Served.

Total Population: 800 Persons
Total Area: 50 Acres
Number Of Subareas: 5
Shelter Location: Center Of Area 1.

FIG. 9.01   HYPOTHETICAL AREA SERVED BY SHELTER

250
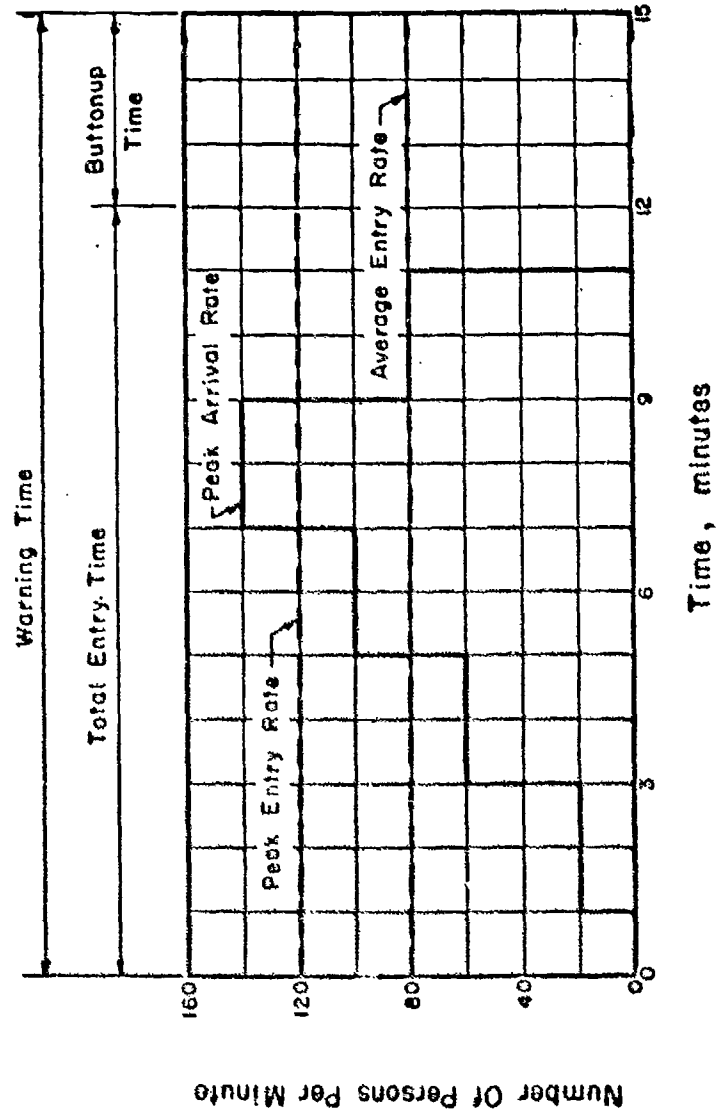
FIG. 9.02 HISTOGRAM OF ARRIVAL RATE VERSUS TIME
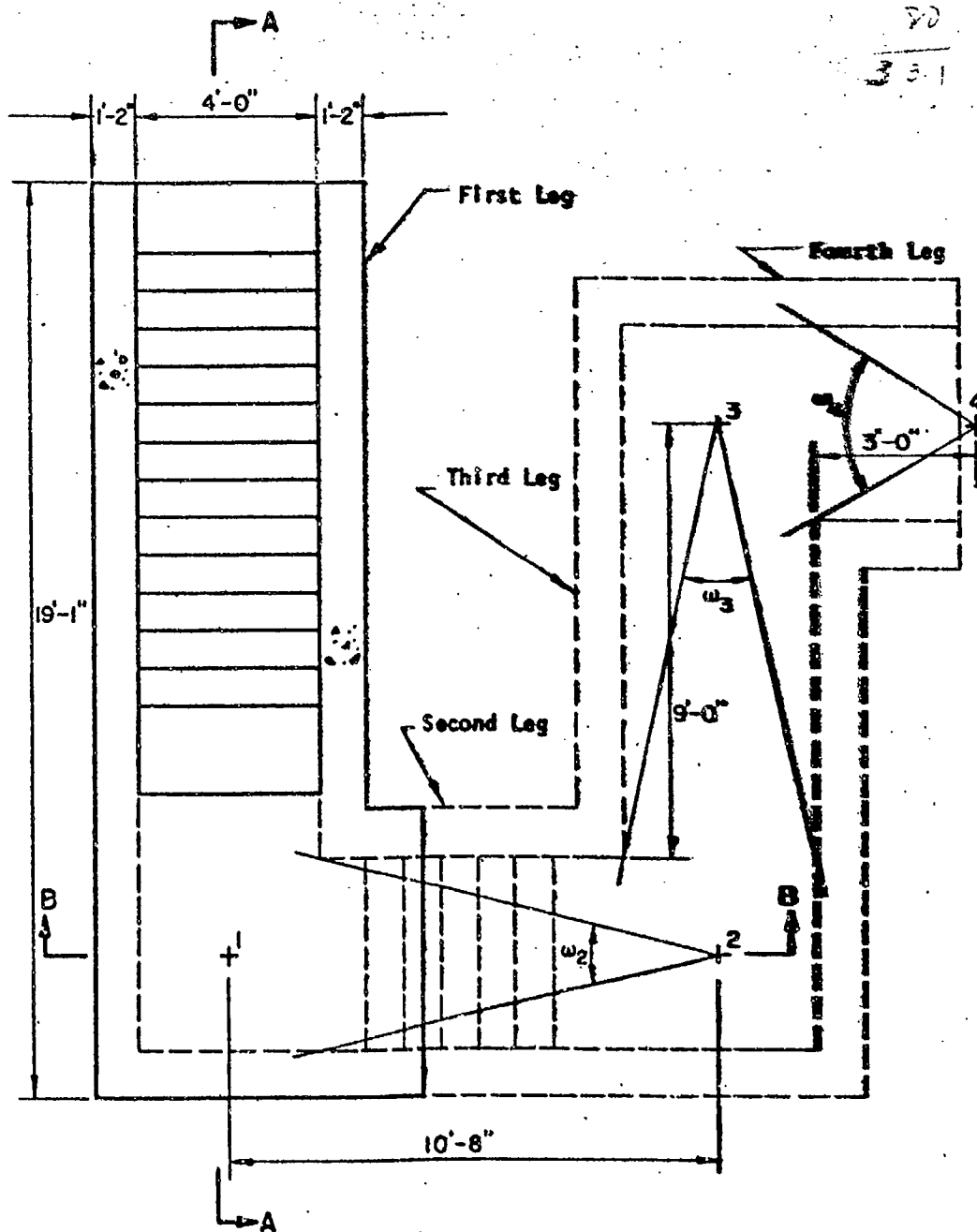
FIG. 9.03 PRELIMINARY ENTRANCE CONFIGURATION - PLAN VIEW
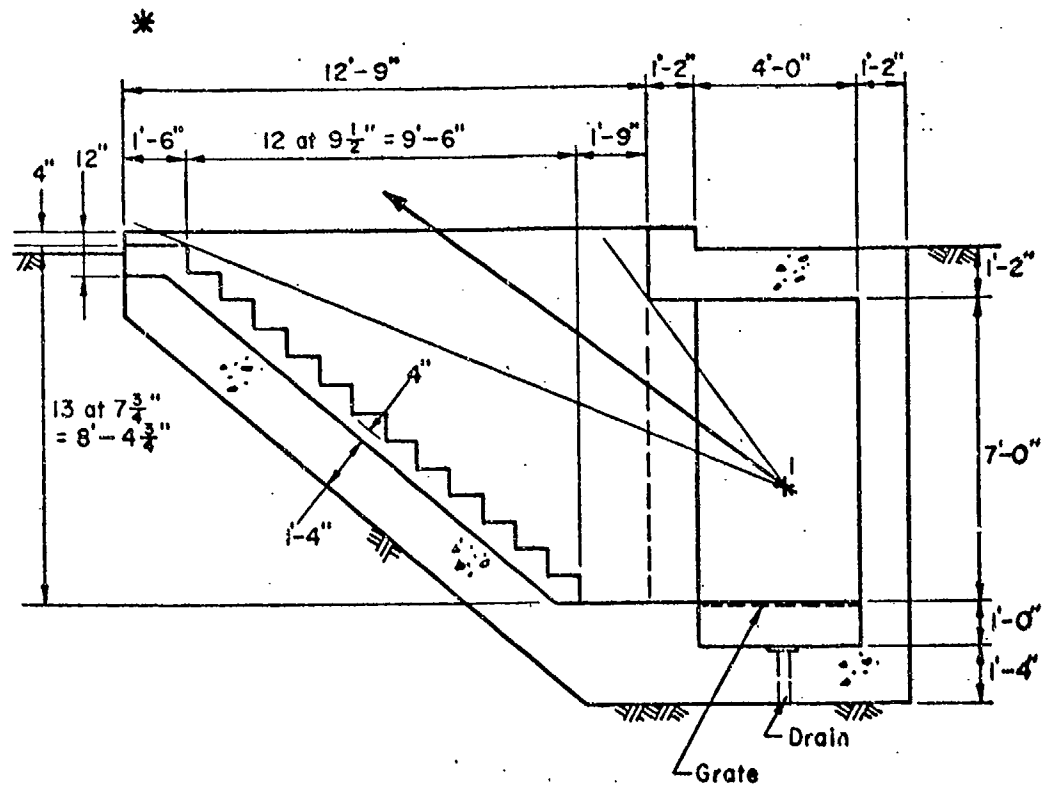
Case I Orientation

FIG. 9.04   PRELIMINARY ENTRANCE CONFIGURATION, SECTION A-A
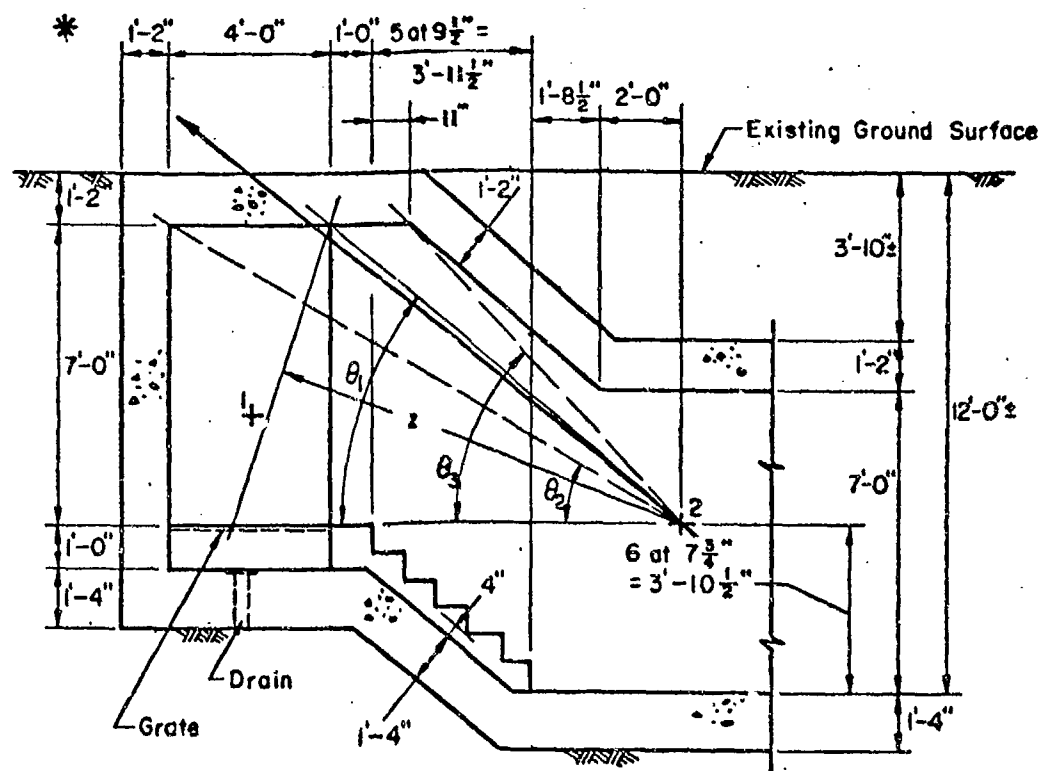
Case 2 Orientation

FIG. 9.05 PRELIMINARY ENTRANCE CONFIGURATION, SECTION B-B
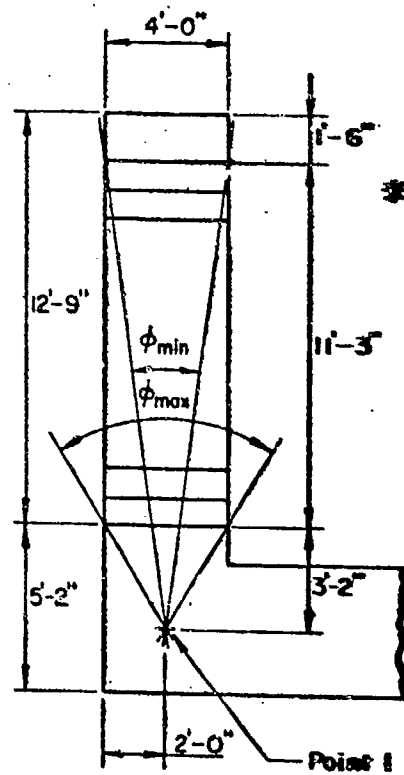
PLAN VIEW
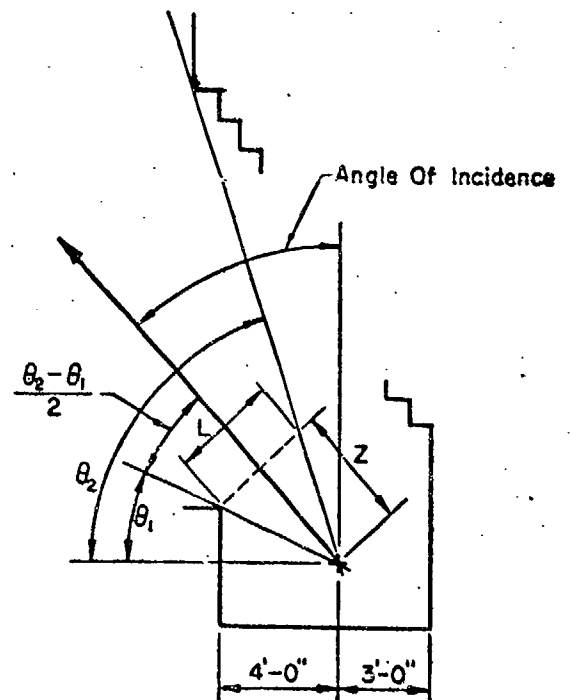
VERTICAL SECTION
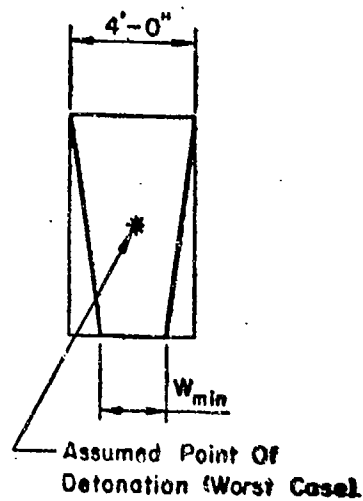
OPENING AS VIEWED
FROM POINT I

FIG. 9.06   DATA REQUIRED FOR CALCULATION
OF SOLID ANGLE FRACTION SUBTENDED BY
OPENING AT POINT I
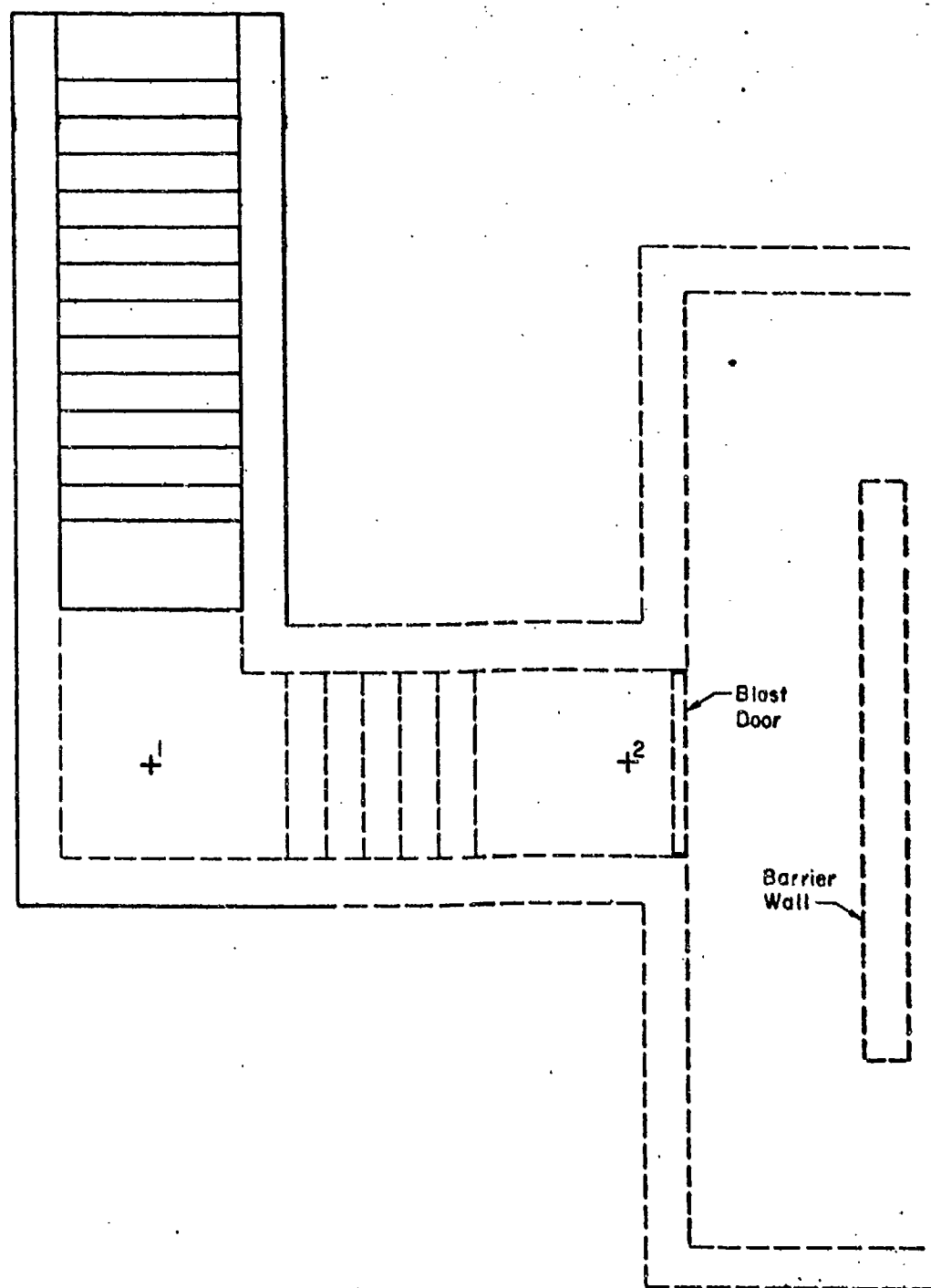
FIG. 9.07 ALTERNATE ENTRANCE CONFIGURATION EMPLOYING BARRIER WALL

256
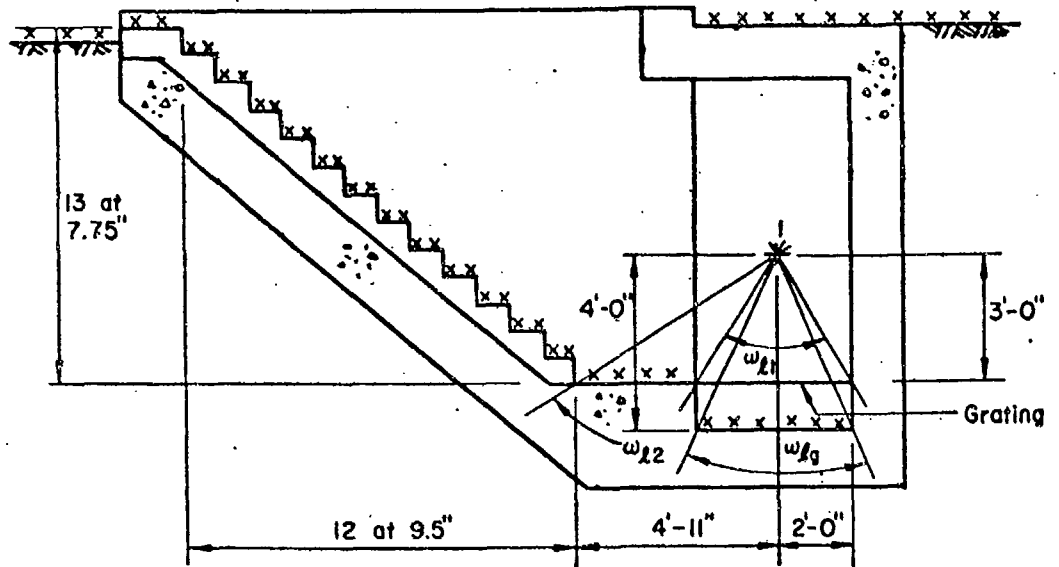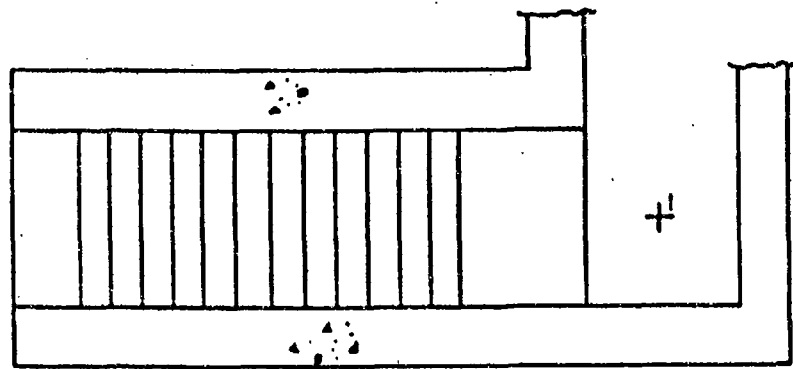
VERTICAL SECTION

PLAN VIEW

FIG. 9.08 GROUND DIRECT CONTRIBUTION AT POINT 1 FROM LANDING

Plane Of Detector

Idealized Plane Of
Contamination On Stairs

7'-9"

$L_2/2$

ω_{s2}

θ

ϕ

39.2°

arc tan $\frac{7.75}{9.50}$ = 39.2

$W/2$

ω_{s1}

Z

9'-6"

4'-11"
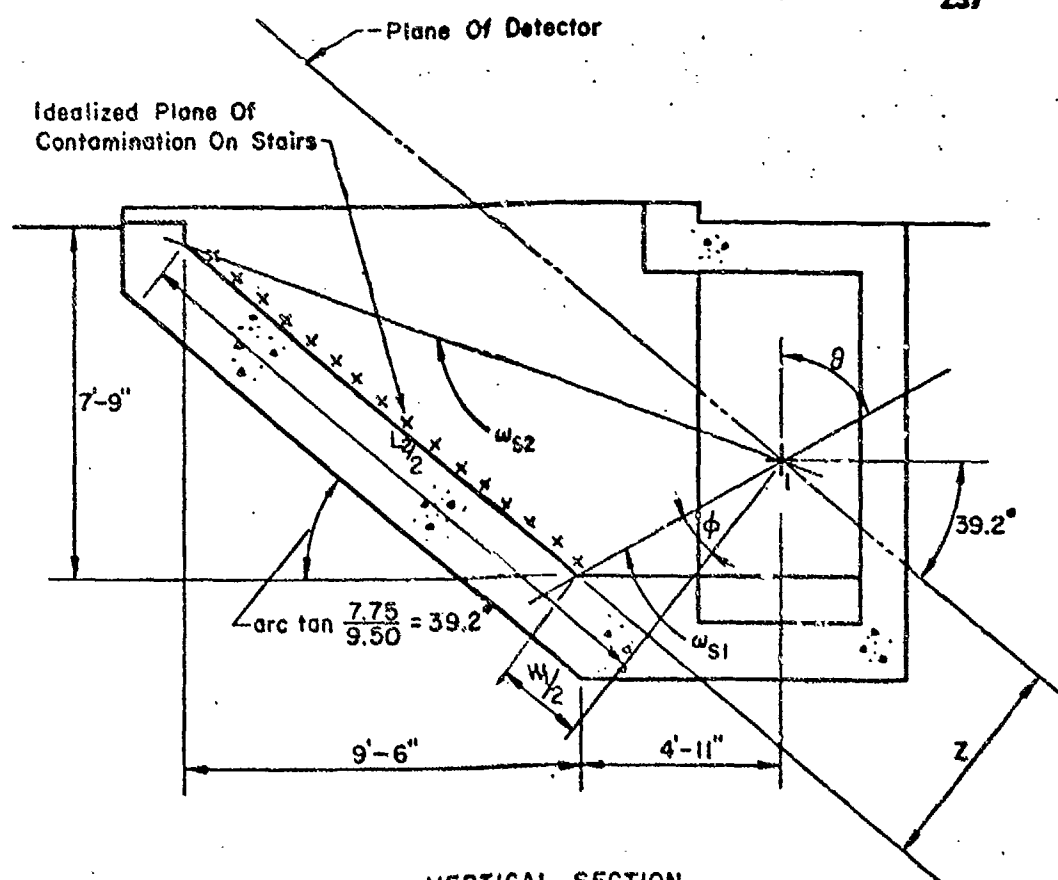
VERTICAL SECTION
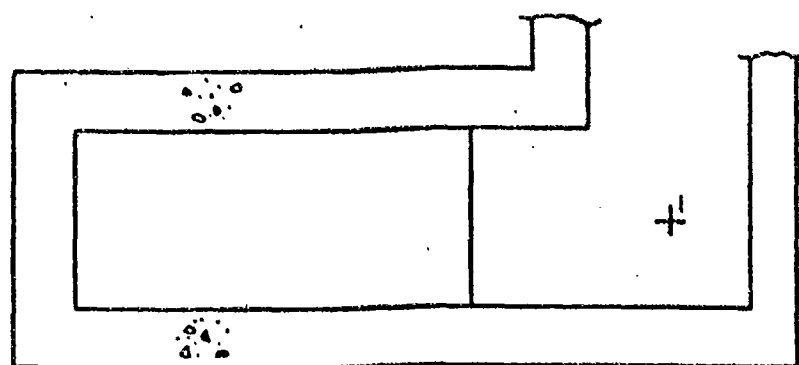
PLAN VIEW

FIG. 9.09 GROUND DIRECT CONTRIBUTION AT POINT 1 FROM STAIRS

258
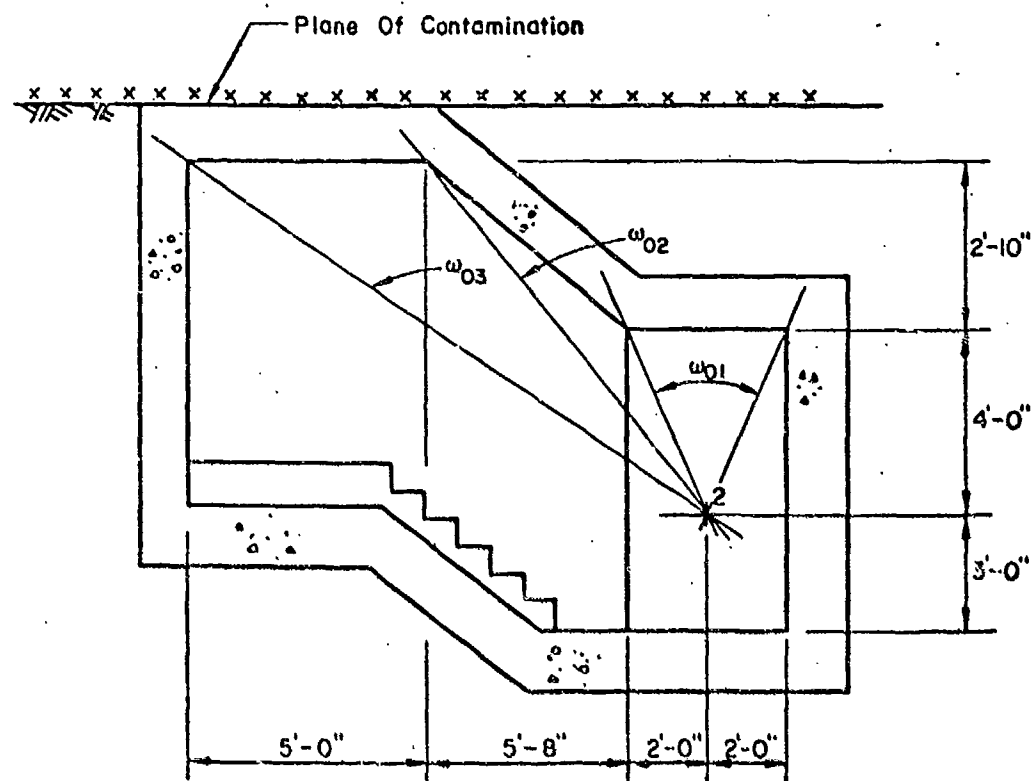
FIG. 9.10   OVERHEAD CONTRIBUTION AT POINT 2
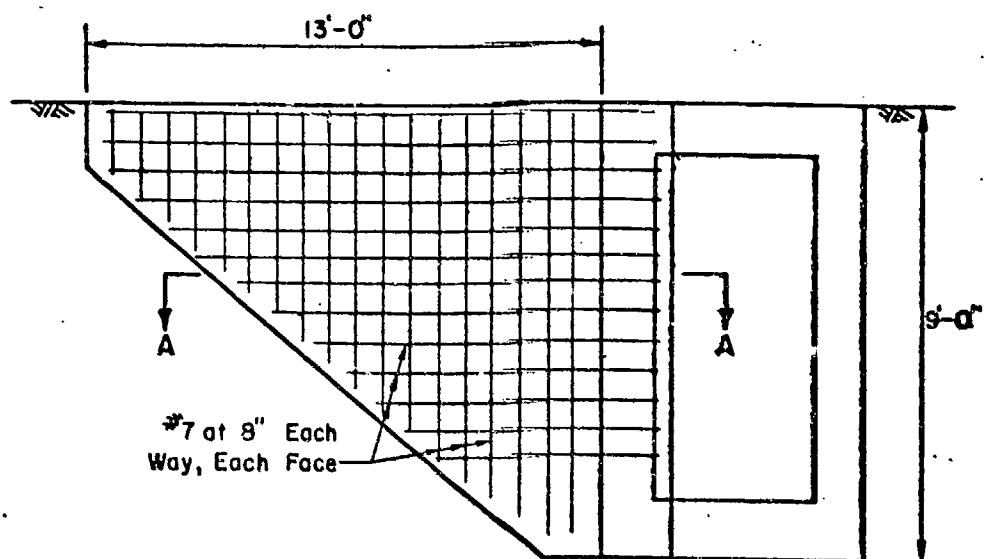
Elevation Of Stairway Wall

13'-0"

9'-0"

#7 at 8" Each Way, Each Face

A   A
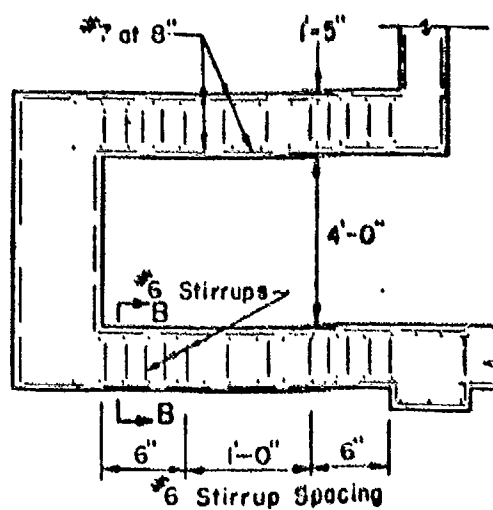
Section A-A

(Typical Transverse Section
Of Exterior Stairway Walls)

#7 at 8"

1'-5"

4'-0"

#6 Stirrups

B

L B

6"   1'-0"   6"

#6 Stirrup Spacing
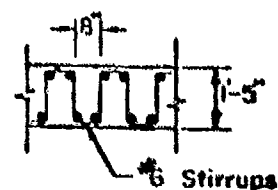
Section B-B
(Stirrup Detail Shown)

8"

1'-5"

#6 Stirrups

FIG. 9.11 REINFORCEMENT IN EXTERIOR STAIRWAY WALLS
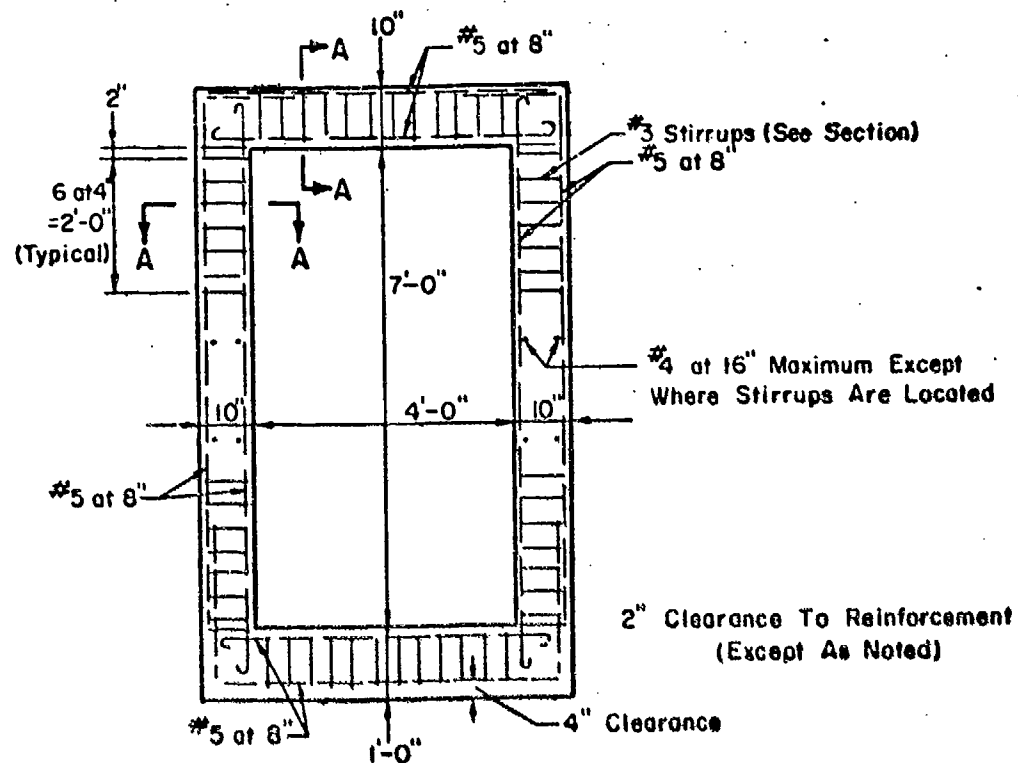
Transverse Section
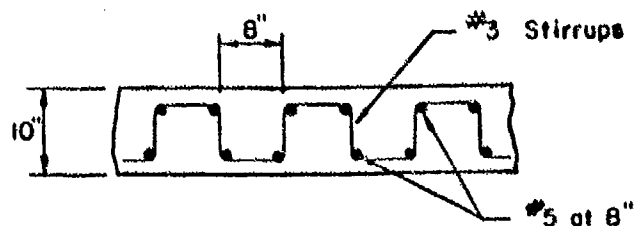
Section A-A
(Stirrup Detail Shown)

FIG. 9.12   REINFORCEMENT IN CORRIDOR SECTION

Interior Stair Section

A

1'-0"

6'-10"

8'-10"

1'-2"

A

#8 at 6½"

*(See Note)

2'-0"

#8 at 5"
Vertical

1'-2"   4'-0"   1'-2"

4" Clearance

#8 at 6½"

#3 Stirrups at 4"
Roof and Floor

2" Clearance To Reinforcement
(Except As Noted)

4 at 16" Maximum Except At
Stirrups (Horizontal)
8 at 5" Vertical

*NOTE:
#3 Stirrups at 5" Typical,
With Stirrup Detail Similar
To That For Corridor
Section Except That Leg
Spacing Corresponds To Main
Reinforcement Spacing.

Section A-A

FIG. 9.13 REINFORCEMENT IN INTERIOR STAIR SECTION

262
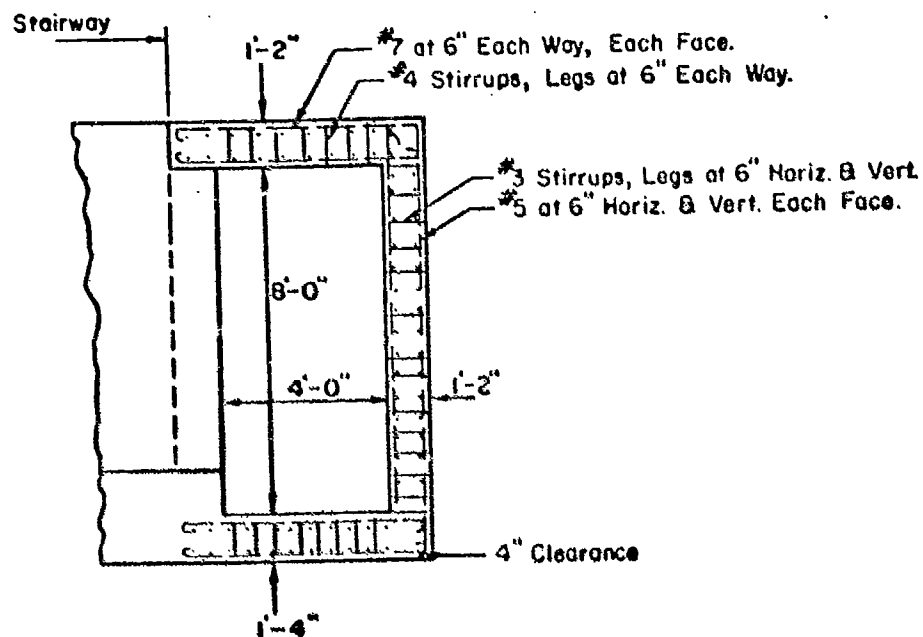
FIG. 9.14 REINFORCEMENT IN LANDING

0.25
5.83"
14"

Door Make-up

6 B 8.5

Edge Channel 6 x 2 [8.2

10 x 8 WF 33

Bottom Flange Removed On One
Side For Casters To Drop In.

Section A-A

10 x 8 WF 33
Sealing Gasket
Door
Caster
A
A
Entrance Wall
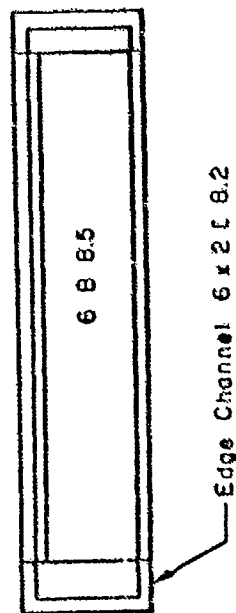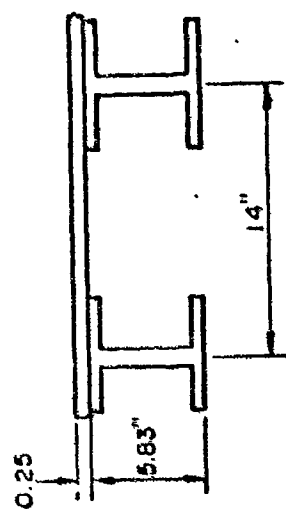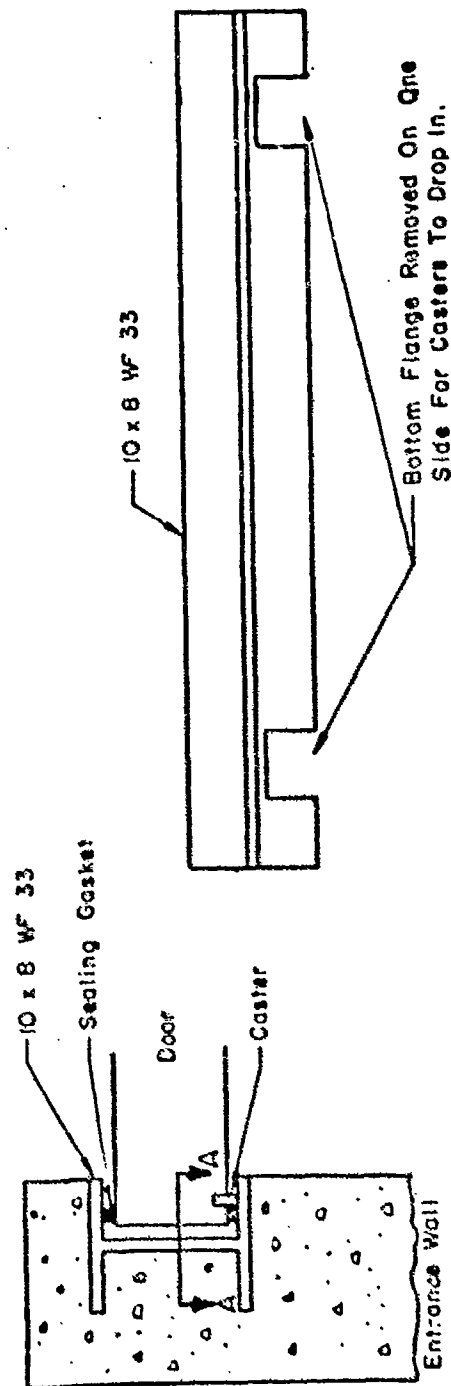
Track In Entrance Wall

FIG. 9.15 TRACK FOR EXTERIOR DOOR

264

10 x 8 WF 33

Edge Channel 6 x 2 [8.2

Casters

Notches In Bottom Flange To Receive Casters.
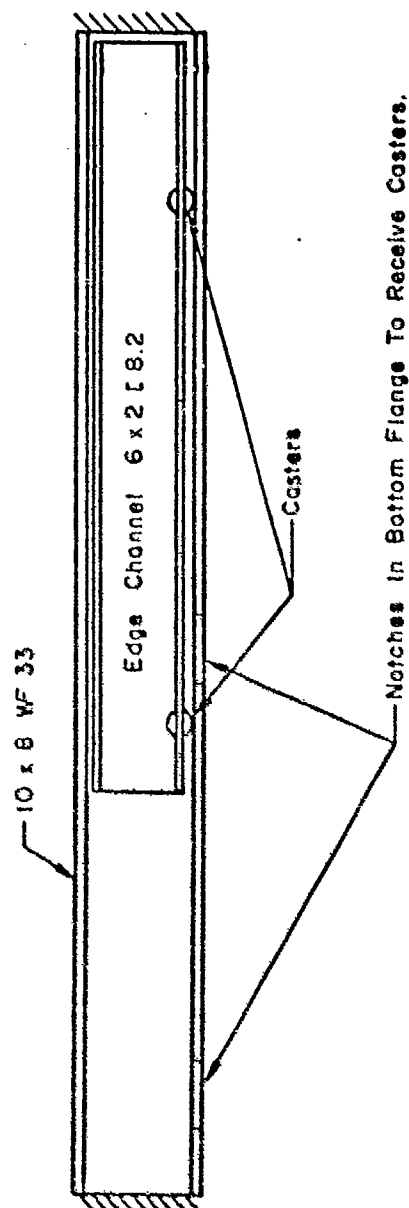
Note:
1.— Casters Spaced So That Door Is Stored
    In Position Illustrated.
2.— Notches In Flange Spaced To Receive Casters
    When Door Reaches Closed Position.

FIG. 9.16 EXTERIOR DOOR AND TRACK
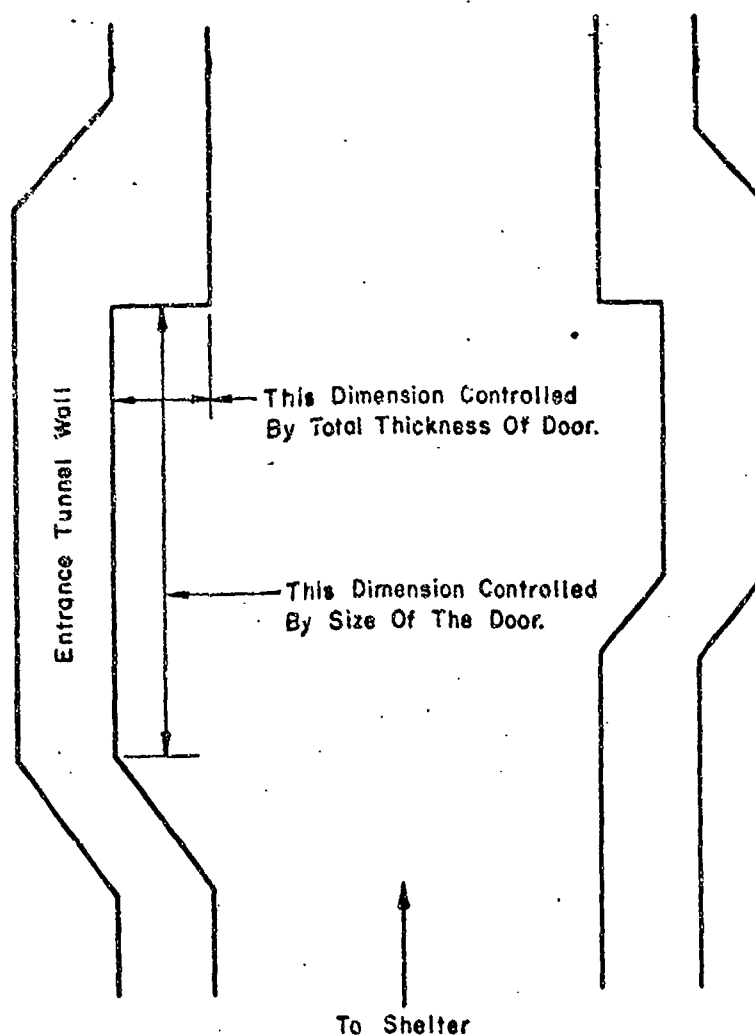
FIG. 9.17   RECESS FOR HINGED CORRIDOR DOOR

266

Clearance As Required To Clear
Opening When Door Is Rotated.

Channel

Drilled Hole To Receive Pins.

Tunnel
Wall

$\frac{1}{4}$" Maximum
Clearance

ST 7 WF

Hollow Slotted Tube
To Hold Pin

Structural Tubing Door

Welded Connection

Gasket Seal

Hinge

Tunnel
Wall
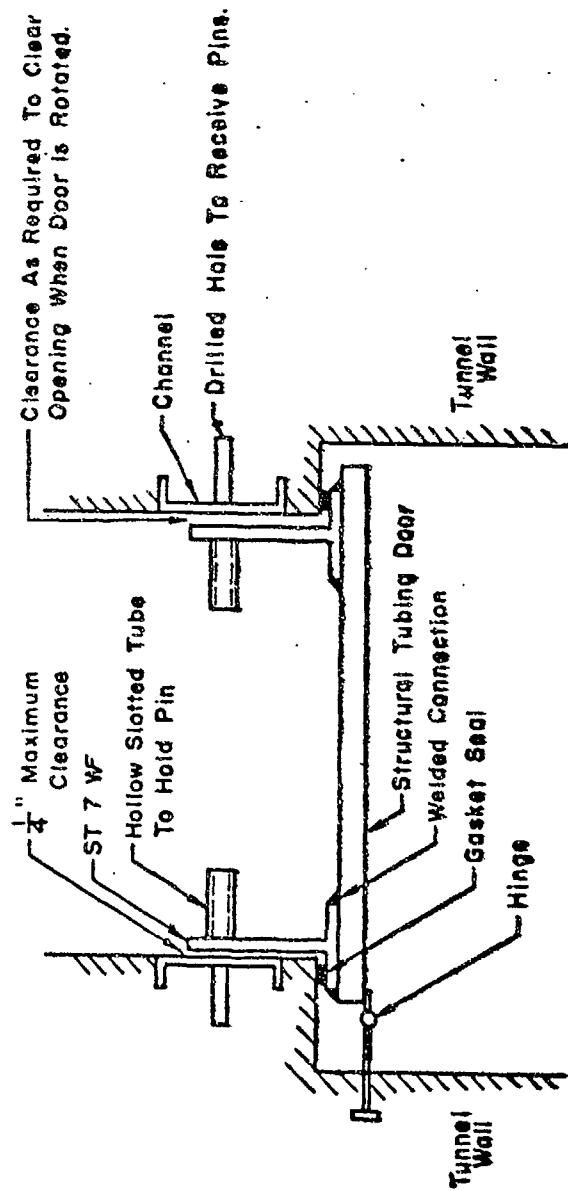
Note:
1.- Pins Provided As Follows,
   3 On Each Long Side
   2 On Each Short Side
2.- ST 7 WF Required All The Way
   Around Inside Of Door.

FIG. 9.18   INTERIOR DOOR

APPENDIX A

PROBABILITY OF DESTRUCTION AND THE DESIGN OF PROTECTIVE STRUCTURES

J. T. Hanley

A.01 INTRODUCTION

An understanding of the concepts of probability theory is essential to a thorough understanding of what is involved in the design of structures to resist attack by nuclear weapons. It is important, first, to recognize that in the design of conventional structures we do, in fact, accept some probability of destruction. This may be done knowingly as in the case of earth dams or unwittingly as in the case, say, of a department store.

There are forces and conditions to which all conventional structures may be subjected for which they were not designed. Every year, homes and other structures are destroyed by flood, wind and earthquake forces for which those structures were not designed, and the question may be asked, "Why weren't those structures designed to withstand those forces?" The answer is that it is not economical to design a house, for example, to withstand the maximum wind forces produced by a tornado especially since the probability that any given home will be subjected to such forces is quite small. It is literally cheaper to accept the probability of destruction of the house (and even the possible loss of lives) and rebuild those destroyed than it is to design all homes as "cyclone cellars."

This judgment is not often made knowingly and was not made specifically by engineers. In fact, it has been made unconsciously by the society as a whole. If an individual wants a structure designed to withstand maximum hurricane or tornado wind force he can get it, but it will cost considerably more than one which was designed in a conventional manner.

In some areas where high winds, high water and/or earthquakes are common occurrences, the building codes require that some resistance against those forces be designed into the structure. However, even in

those areas structures are seldom designed to withstand the maximum forces to which they might be subjected. There are other areas in the country where despite the frequent occurrence of destructive natural forces no provision is made in the design of structure for those forces. In these areas the basic reason for not doing so is simply that it would cost too much.

In the design of protective structures the fact that some probability of destruction must be accepted is brought out into the open. The following is a development of some of the basic concepts involved.

A.02 THE CIRCULAR GAUSSIAN DISTRIBUTION

If a weapon is fired at a target the probability that it will land within a given range of the aiming point may be determined from probability theory. To approach the problem heuristicly, consider a rifleman shooting at a target. It seems reasonable to assume that if a rifleman were to shoot at the target a large number of times the distribution of shots about the bullseye would approach the normal error distribution on any diameter through the center of the target (Fig. A.01). This is tantamount to assuming that:

1. A large number of small errors are present in any single observation (i.e., shot).

2. An error to the right and an equal error to the left of the bullseye are equally probable. That is, there is no systematic error such as the sight being off which could be compensated for anyway.

3. The probability of a small error is greater than the probability of a large error in a given shot.

These assumptions are not always valid, but there is ample evidence to indicate that they are in this case. From these assumptions the so-called Gaussian distribution, or normal error function, was developed which has the following form (See Ref. A.01 for development):

$$z = \frac{h}{\sqrt{\pi}} e^{-h^2 r^2} \tag{1}$$

where h = a function of the standard deviation

r = the deviation from the mean, i.e., distance from the bullseye.

This function is the bell-shaped distribution curve shown in Fig. A.01. Note that the curve has the following properties;

1. It is symmetrical about the Z-axis.
2. The maximum ordinate occurs at $r = 0$ and has the value, $\frac{h}{\sqrt{\pi}}$
3. Differentiating the function twice with respect to the deviation and setting the second derivative equal to zero, it is shown that the curve has points of inflection at

$$r = \pm \frac{1}{h\sqrt{2}} \tag{2}$$

If we make one more assumption, as previously indicated, that the error is not a function of θ (see Fig. A.02), then the probability that a shot will fall within a circle of radius r may be expressed as

$$p = \frac{h}{\sqrt{\pi}} \int_0^{2\pi} \int_0^r r e^{-h^2 r^2} \, dr \, d\theta \tag{3}$$

Integrating first with respect to θ

$$p = 2h\sqrt{\pi} \int_0^r r e^{-h^2 r^2} \, dr$$

Then with respect to r

$$p = 2h\sqrt{\pi} \left[\frac{-e^{-h^2 r^2}}{2h^2} \right]_0^r$$

$$p = \frac{\sqrt{\pi}}{h} \left[1 - e^{-h^2 r^2} \right] \tag{4}$$

To evaluate to the constant "h" it is necessary only to note that, by definition, the probability that a shot will fall within a circle of radius $r = \infty$ is a certainty, or 1.

Thus

$$h = \sqrt{x}$$

and

$$p = 1 - e^{-x r^2} \tag{5}$$

The probability that a shot will fall outside of a circle of radius r is;

$$S = 1 - p = e^{-x r^2} \tag{6}$$

where S = survival probability

A.03 A POINT TARGET AT THE DGZ

Let us define the "radius of damage" (R_d) to be that radius from a given yield weapon at which a specified amount of damage will be produced in a given structure. If the structure is assumed to be at the bullseye, or in protective construction parlance, if the structure is assumed to be at the designated ground zero (DGZ), then a weapon which falls outside of the circle whose radius is equal to R_d cannot cause the specified damage. Conversely, a weapon which falls inside the circle whose radius is equal to R_d will cause at least the specified damage to the structure.

However, equations (5) and (6) are not very useful in the form presented. Both equations may be expressed in terms of the circular error probable (CEP) which is defined as the radius within which 50% of the weapons fired will fall. Obviously the CEP varies from one weapon system to another. For example, weapons delivered by dive bomber will have a smaller CEP than weapons delivered by ICBM.

Sec. A.04

Since

$$(0.5) = e^{-\pi(CEP)^2}$$

$$\ln(0.5) = -\pi(CEP)^2 \qquad (7)$$

Further, in general:

$$\ln(S) = -\pi R_d^2 \qquad (8)$$

Dividing equation (8) by (7)

$$\ln(S) = \left(\frac{R_d}{CEP}\right)^2 \ln(0.5)$$

and

$$S = (0.5)^{\left(\frac{R_d}{CEP}\right)^2} \qquad (9)$$

By definition, then

$$p = 1 - (0.5)^{\left(\frac{R_d}{CEP}\right)^2} \qquad (10)$$

Note that the CEP bears a similar relationship to the circular Gaussian distribution that the standard deviation does to the normal error distribution; both the CEP and the standard deviation are measures of the precision of the system involved.

A.04 EFFECT OF TARGET DIMENSIONS

In the preceding discussion it was assumed that the target structure was a point at the DGZ. Since structures have dimensions, how reasonable is this assumption?

Consider a structure which is circular in plan. For such a structure the probability of any part of the structure will be subjected to say a peak pressure sufficient to cause some specified damaged to that portion may be expressed as:

$$p = 1 - (0.5)^{\left(\frac{R_d + R_s}{CEP}\right)^2}$$

where R_d = radius of damage for the specified criterion

            R_S = radius of the structure

or

$$p = 1 - (0.5)^{\left(\frac{R_d}{CEP}\right)^2 \left(1 + \frac{R_S}{R_d}\right)^2}$$

It is apparent that if $\dfrac{R_S}{R_d}$ is small the probability may reasonably be expressed as

$$p = 1 - (0.5)^{\left(\frac{R_d}{CEP}\right)^2}$$

Thus, if the dimensions of the structure are small compared to the "radius of damage", the structure may be considered a point target. It is also important to note that under these conditions the free-field pressure, thermal, neutron and gamma flux are almost constant over the range represented by the dimensions of the structure.

A.05 POINT TARGET AWAY FROM THE DGZ

If the target structure is not located at the assumed DGZ the probability of destruction may be calculated by evaluating the integral

$$p = \int_0^{2\pi} \int_0^r f(r,\theta) \; r \, dr \, d\theta$$

This can become a considerable exercise in mathematics. At this point it is convenient to turn to a graphical solution. Fig. A.03 is a plot of equation (10). Note that:

    1. The center is the DGZ.

    2. All cells within the 22nd ring are assigned the value of 0.001; i.e., the probability that a weapon will fall in any one of those cells is 1 in 1000.

    3. The sum of the values of all cells shown is 1, or certainty.

    4. There is a scale in units of CEP's in the upper right hand corner.

5. There is a tabulation by ring number of the number of
   cells in each annulus and the total number of cells
   inscribed by any ring.

To use this figure, it is necessary first to locate the target
with respect to the DGZ. This is done by plotting a point on any radius
at a distance d/CEP from the origin, where d is the distance from the
structure to the assumed DGZ. Then using that point as the center inscribe
a circle of radius R_d/CEP about it. The probability that the point target
will be destroyed is the sum of the values of the cells inscribed.

As an example, consider a structure located 15,000 ft. from the
DGZ. A 100 psi incident overpressure will cause some specified amount
of damage to the structure. Assume that a missile facility, located at
the DGZ, will be attacked by a 10 megaton yield weapon delivered by a
system with a 5000 ft. CEP. What is the probability that the structure
will be subject to at least 100 psi?

First, the structure must be located on any radius at a distance
of d/CEP = 3 from the DGZ, as shown in Fig. A.03. Next a circle whose
radius is equal to R_d/CEP = 7500/5000 = 1.50 is drawn about the target
structure (the range of 100 psi from a surface burst of a 10 MT weapon
is 7500 ft.). The sum of the values of the cells inscribed by the circle
so drawn is about 0.0265; i.e., the probability of receiving 100 psi or
more is about 2.65 in 100, and therefore the probability of not receiving
such pressures is about 97.35 in 100.

It is apparent that for any facility which is not in itself a
target for attack, dispersal or locating the facility at some distance
from the assumed DGZ will reduce the probability of destruction greatly.
Specifically, anytime

$$\frac{d}{CEP} - \frac{R_d}{CEP} \geq 3.2,$$

the probability of destruction is less than 1 in 1000.

A.06 LINE TARGETS

For line targets, such as power, communications and water lines,
the calculation of the probability of destruction is relatively a simple

matter graphically. First, plot the line on a graphical plot of the
circular Gaussian distribution. Then construct lines on either side
parallel to the target line at the distance of R_d/CEP and count the cells
inscribed.

An example is shown in Fig. A.04, where it is assumed that a
power line buried at an average depth of 6 ft. runs into a point target
which is assumed to be a target for nuclear attack. Other assumptions
are:

1. Weapon yield; 10 MT.

2. Radius of damage; 1.5 crater radii.

3. CEP; 6000 ft.

For a 10 MT weapon, 1.5 crater radii is equal to about 1800 ft.
Thus, R_d/CEP = 0.3.

Counting the cells between these lines it is found that for
these assumptions, the probability of destruction is about 0.20, or 20%.

In this case some interesting questions might be asked. First,
what design overpressure should be used for the point target to obtain
an equal probability of destruction for the target structure as for the
incoming power line? This might be a logical question in the case of an
unmanned communications facility which would be useless without power.

By inspection of Fig. A.04, the circle R_d/CEP will lie between
the 8th and 9th rings (i.e. total inside 8th ring is 0.175 and total
inside 9th ring is 0.222). Therefore, R_d/CEP = 0.59 and R_d = 3540 ft.
From Fig. 2-7 of Ref. A.02, the overpressure associated with this range
from a 10 MT surface burst is about 700 psi. Thus, to obtain the same
probability of survival for the point target and the incoming power
line, the target structure should be designed to withstand 700 psi.

If the power line were duplicated, i.e., if another power line
were brought into the structure from the other side, what is the proba-
bility that both will be knocked out by the same weapon? Since both
lines terminate at the DGZ the answer may be obtained analytically:

$$p = 1 - (0.5)^{\left(\frac{R_d}{CEP}\right)^2} = 1 - (0.5)^{(0.3)^2}$$

3. the CEP of the weapon system is 3000 ft.,

4. the center line of the first flight of stairs is perpendicular to the line from the DGZ to the shelter, and,

5. the worst case orientation occurs when the point of detonation can be seen from a point three feet above the landing at the bottom of the first flight of stairs.

For the weapon to be seen from this point, the point of detonation must fall within an angle, φ (variable), in the horizontal plane (Plan View) and within the angle $(\theta_2 - \theta_1)$, in the vertical plane (Section B-B). Further, the slant range, R, within which the weapon must fall is 4600 ft.

Ignoring the probable error in burst height and assuming that the weapon has a probability of 1 of detonating at an altitude, HOB, between the limits,

$$HOB = R \cos \theta_1$$

and

$$HOB = R \cos \theta_2,$$

an upper limit to the probability of the worst case may be obtained.

The projection of the spherical surface defined by R, θ_1, θ_2, and φ on the horizontal plane may be plotted on the graphical representation of the circular Guassian error distribution, if the orientation of the entrance structure with respect to the DGZ is known.

From Fig. A.05

$$\theta_1 = \arctan \frac{2}{4.5}$$

$$\sin \theta_1 = \frac{2}{\sqrt{(2)^2 + (4.5)^2}} = 0.407$$

$$p = 1 - 0.9395 = 0.0605$$

or

$$p = 6 \text{ in } 100$$

Under these conditions the structure would have to be designed for a survival probability of 0.94 to obtain a "balanced" design. If it is not feasible to design the structure to withstand the surface burst at a distance of 1.5 crater radii the duplicate power line cannot be justified.

A.07 THE USE OF PROBABILITY STUDIES IN DESIGN

As implied by the previous problem, a rational approach to the design of protective structures would require that the probability of "failure" in various "modes" be balanced. A structure might withstand a given overpressure and fail to protect its occupants against prompt nuclear radiation for example. Or, it could fail in other ways depending on the mission of the structure.

However, the problem of balancing the probabilities of failure in various modes can be quite complex because the various effects do not scale from one yield to the next in the same way. The distance for a given peak pressure scales in accordance with the cube root of the yield while prompt nuclear radiation scaling is considerably more complicated. The net result is that as a practical matter in design the structure is generally designed first to resist the blast effects of a nuclear attack and then investigated to determine whether the shielding afforded is adequate.

It has been customary to assume the "worst case" orientation to determine whether the shielding afforded is adequate. This may not always be justified. For example, consider the entrance structure shown in Fig. A.05. Assume that:

1. the shelter is designed for 50 psi overpressure and associated effects from a 1 MT weapon,

2. the shelter is located at a distance of 6000 ft. from the OGZ,

3. the CEP of the weapon system is 3000 ft.,

4. the center line of the first flight of stairs is
    perpendicular to the line from the DGZ to the
    shelter, and,

5. the worst case orientation occurs when the point of
    detonation can be seen from a point three feet above
    the landing at the bottom of the first flight of stairs.

For the weapon to be seen from this point, the point of detona-
tion must fall within an angle, φ (variable), in the horizontal plane
(Plan View) and within the angle $(\theta_2 - \theta_1)$, in the vertical plane (Section
B-B). Further, the slant range, $\tilde{n}$, within which the weapon must fall is
4600 ft.

Ignoring the probable error in burst height and assuming that
the weapon has a probability of 1 of detonating at an altitude, HOB,
between the limits,

$$HOB = R \cos \theta_1$$

and

$$HOB = R \cos \theta_2,$$

an upper limit to the probability of the worst case may be obtained.

The projection of the spherical surface defined by R, θ_1, θ_2,
and φ on the horizontal plane may be plotted on the graphical representa-
tion of the circular Guassian error distribution, if the orientation of
the entrance structure with respect to the DGZ is known.

From Fig. A.05

$$\theta_1 = \text{arc tan } \frac{2}{4.5}$$

$$\sin \theta_1 = \frac{2}{\sqrt{(2)^2 + (4.5)^2}} = 0.407$$

$$\theta_2 = \text{arc tan } \frac{12'-10''}{4.5}$$

$$\sin \theta_2 = \frac{12.83}{\sqrt{(12.83)^2 + (4.5)^2}} = 0.945$$

$$\varphi_{max} = 2 \text{ arc tan } \frac{2}{2} = 90^{\circ}$$

$$\varphi_{min} = 2 \text{ arc tan } \frac{2'-0''}{12'-10''} = 17.6^{\circ}$$

Then

$$\frac{R \sin \theta_1}{CEP} = \frac{4600}{3000} (0.407) = 0.625$$

$$\frac{R \sin \theta_2}{CEP} = \frac{4600}{3000} (0.945) = 1.45$$

$$\frac{d}{CEP} = \frac{6000}{3000} = 2$$

These data are plotted in Fig. A.06, from which an upper limit to the probability of the worst case is

$$p \cong 0.003$$

or, the probability of the worst case is about 3 in 1000.

A byproduct of this procedure is the obvious conclusion that if a logical decision can be made as to the location of the DGZ, the probability of the worst case can be minimized by orienting the entrance so that the opening faces in the opposite direction.

The probability that the structure will be subjected to the design overpressure can also be determined graphically assuming that the structure is a point target, which is not unreasonable in most cases.

This is accomplished simply by inscribing a circle of radius $\frac{R_d}{CEP}\left[=\frac{4600}{3000}=1.53\right]$ about the point target, and counting the cells circumscribed. The probability of this event is

$$p \cong 0.2$$

or, about 2 in 10.

It is apparent that, in general, the probability of the worst case for prompt radiation is small compared to the probability that the structure will be subjected to overpressures well in excess of the design overpressure.

If the procedure outlined were employed t. attempt to balance the probabilities of exceeding each of the design criteria, it would become clear quickly that a different "balance" would be required for each height of burst. Therefore, a "balanced design" in the general case is simply not possible. This is not to say that the question should not be investigated nor that probability studies are useless. Such studies often bring to light facts which are not as intuitively obvious as the fact that shelter entrance structures should face away from the most likely location for ground zero.

A.08 REFERENCES

A.01   Beers, Yardley, "Introduction to the Theory of Error,"
       Addison-Wesley Publishing Co., Inc., 1957.

A.02   Newmark, Hansen and Associates, "Protective Construction
       Review Guide - (Hardening)" Vol. I. Office of the Assistant
       Secretary of Defense, Installations and Logistics, June 1961.

$$z = \frac{h}{\sqrt{\pi}} (e)^{-h^2 r^2}$$
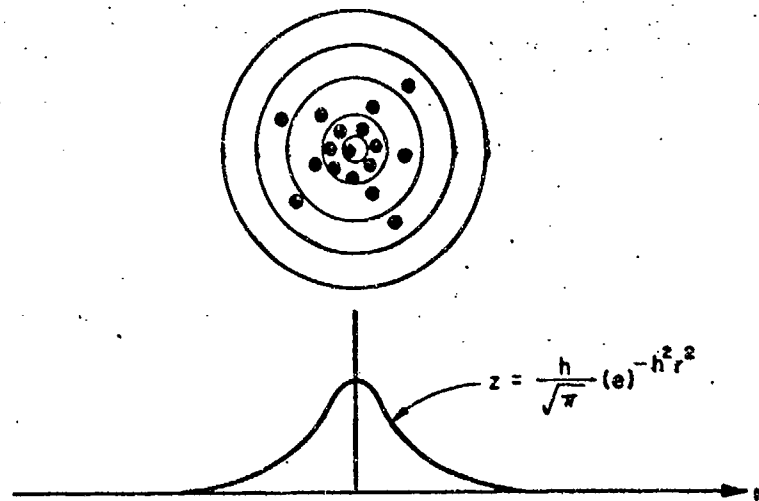
FIG. A.01 DISTRIBUTION OF SHOTS ABOUT BULLSEYE

$$\Delta p = \frac{h}{\sqrt{\pi}} (e)^{-h^2 r^2} r \, dr \, d\theta$$
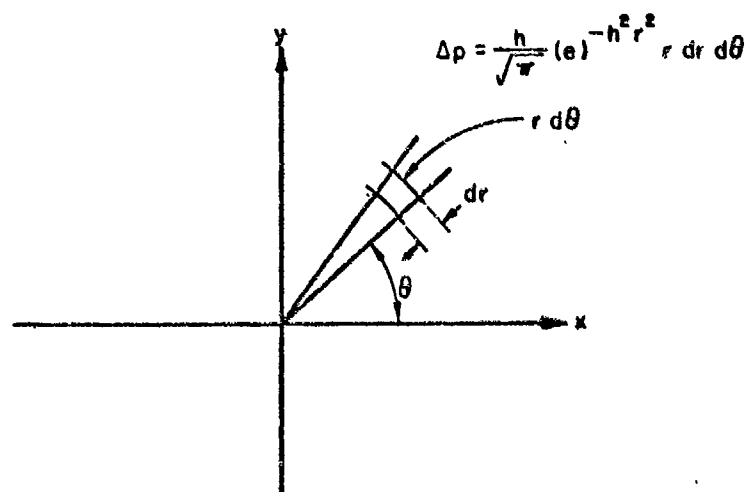
FIG. A.02 BASIS FOR CALCULATION OF CIRCULAR

GAUSSIAN DISTRIBUTION

Ring Number	Number In Ring	Total Inside Ring	Ring Number	Number In Ring	Total Inside Ring	Ring Number	Number In Ring	Total Inside Ring
1	1	1	9	47	222	17	68	721
2	7	8	10	52	274	18	66	787
3	13	21	11	56	330	19	62	849
4	19	40	12	60	390	20	57	906
5	25	65	13	63	453	21	48	954
6	31	96	14	65	518	22	36	990
7	37	133	15	67	585	23	36/4	999
8	42	175	16	68	653	24	10/10	1000

CELLS OF EQUAL PROBABILITY

FIG. A.03 POINT TARGET AWAY FROM THE DGZ

Ring Number	Number In Ring	Total Inside Ring	Ring Number	Number In Ring	Total Inside Ring	Ring Number	Number In Ring	Total Inside Ring
1	1	1	9	47	222	17	68	721
2	7	8	10	52	274	18	66	787
3	13	21	11	56	330	19	62	849
4	19	40	12	60	390	20	57	906
5	25	65	13	63	453	21	48	954
6	31	96	14	65	518	22	36	990
7	37	133	15	67	585	23	36/4	999
8	42	175	16	68	653	24	10/10	1000

CELLS OF EQUAL
PROBABILITY

FIG. A.04 LINE TARGET PROBLEM

Note: φ is Variable

PLAN VIEW

SECTION B-B

SECTION A-A
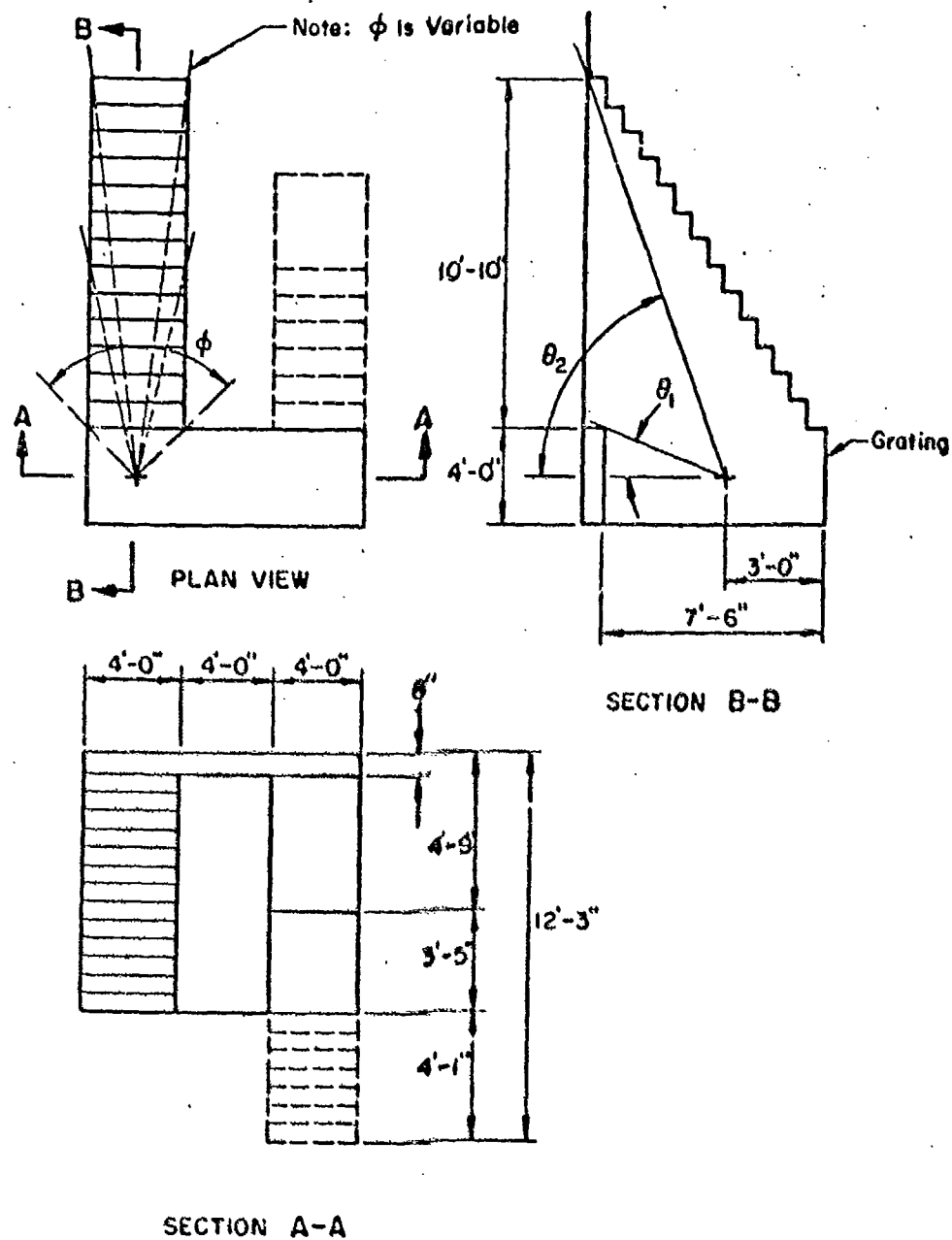
FIG. A.05   OPEN STAIR ENTRANCE CONFIGURATION

A-18

Ring Number	Number In Ring	Total Inside Ring	Ring Number	Number In Ring	Total Inside Ring	Ring Number	Number In Ring	Total Inside Ring
1	1	1	9	47	222	17	68	721
2	7	8	10	52	274	18	66	787
3	13	21	11	56	330	19	62	849
4	19	40	12	60	390	20	57	906
5	25	65	13	63	453	21	48	954
6	31	96	14	65	518	22	36	990
7	37	133	15	67	585	23	36/4	999
8	42	175	16	68	653	24	10/10	1000

CELLS OF EQUAL
PROBABILITY

FIG. A.06 PROBABILITY OF WORST CASE ORIENTATION FOR PROMPT NUCLEAR RADIATION

APPENDIX B

ECONOMIC CONSIDERATIONS

It is axiomatic that costs are as important in the design and construction of protective shelters as in the design and construction of any other type of building. The factors affecting the total cost of a protective shelter can be tabulated as follows:

1) Site
   - (a) Land acquisition
   - (b) Availability of utilities
   - (c) Relocation of utilities
   - (d) Terrain conditions
2) Materials
   - (a) Local availability
   - (b) Austerity of finish
   - (c) Quality
3) Labor
   - (a) Simplicity of construction details
   - (b) Prefabrication of components
   - (c) Use of unskilled personnel
4) Size or Capacity of Structure
5) Multi-purpose Use
6) Inter-relation of Components
7) Degree of Protection

The effect of most of the preceding factors upon the total cost is obvious. Consequently, the only factors discussed herein will be those whose effect either is not obvious or is somewhat different from that in conventional building designs.

One of the most significant economic differences between conventional building design and protective shelter design results from the inter-relationship or inter-dependency of the components of a protective shelter system. This difference is particularly significant when radiation shielding is concerned.

The total dose received by a detector in the shelter is the sum of the prompt and residual doses received through both the entranceways

and the shelter proper. This can best be shown diagrammatically as
follows:

ALLOWABLE TOTAL DOSE

```
                    ALLOWABLE TOTAL DOSE
                             |
              +--------------+--------------+
              |                             |
        Entrance System              Shelter Proper
              |                             |
        +-----+-----+               +-------+-------+
        |           |               |               |
      Prompt     Residual         Prompt        Residual
        |           |               |               |
    +---+---+       |           +---+---+           |
    |       |       |           |       |           |
  Neutron  Gamma  Gamma      Neutron  Gamma       Gamma
```
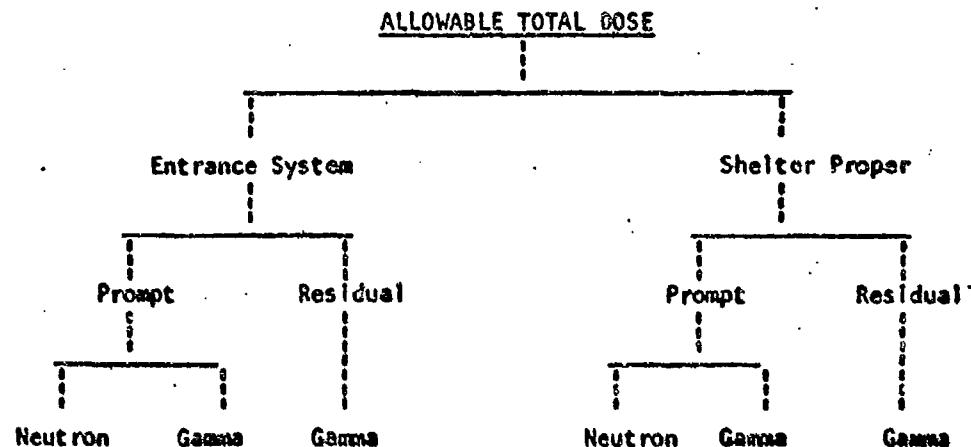
Since there are no limiting doses from the individual contribu-
tions, there are an infinite number of combinations of the various contributions
whose sum will equal the total allowable dose. Thus the shelter designer
must balance the costs of the various components and their shielding
capability. He may find that it is less expensive to place more fill
over the shelter proper, thereby reducing that contribution, than it is
to reduce the entrance contribution by bends, barriers or other means.
The designer may find that the cost of a surface door to keep fallout from
entering the stairwell is less expensive than an extra bend in the corridor
or that the reduction of radiation due to the surface door is sufficient
to permit a greater contribution through the shelter proper with the
consequent need for less overhead fill.

The economic balancing of the various components of the total
shelter system is essential if least cost is to be realized. While the
individual costs of the various components can not be isolated as far
as radiation protection is concerned, it is possible to estimate the
dollar cost per rad (dose) for the various components, i.e., $/Rad for
corridor, for $90°$ bend, for overhead mass thickness. Such cost computa-
tion for a specific shelter will facilitate the determination of the most
economical proportion.

Since the costs of the structural elements are less inter-related
than the radiation attenuation elements, the structural costs of the
components may be more readily isolated. For instance, the cost per foot
of door will be least for an exterior horizontal flush door. The cost
per foot of door increases with the angle of incidence due to the
increased reflected pressure. The total door cost depends not only upon
the cost per foot, but the length of door as well. Thus, since the length
of the horizontal door is the greatest, it is necessary to make total
actual cost comparisons.

In conventional building design it is common practice to reduce
the total cost by using less expensive, but structurally adequate,
materials. It is presumed that austerity is the watchword in any shelter
design. Thus, a designer has little opportunity to reduce the "frills"
and thereby reduce the eventual cost. This is particularly true when
the entrance structure alone is considered.

The designer must always bear in mind that least cost compari-
sons are valid only when the designs compared offer the same degree of
protection or safety. Thus, while a wider entrance structure may be more
economical than two narrower entrance structures with the same total
capacity and radiation protection as the larger structure, the extra
door has an added safety advantage as an emergency escape route.

Unfortunately, there are no hard and fast rules that can be
established to insure minimum cost. The final decision can be made
only when least costs are evaluated with the intangibles that do not
lend themselves to actual costing.

APPENDIX C
SOLID ANGLE AND SOLID ANGLE FRACTION

C.01 SOLID ANGLE

The solid angle is a measure of the field of view occupied by an object or a surface in space as seen from some specified point in space whose position is fixed relative to that object or surface. In solid geometry, the solid angle is measured in steradians and may be defined as the area subtended on the surface of sphere of unit radius by the object or surface.

$\Omega = A$; where Ω = the solid angle

A = the area subtended

(or $\Omega = A/r^2$; if sphere is of radius r)

Consider two spheres of any radius at some distance, d, apart, as shown in Fig. C.01. As seen from the center of sphere A, sphere B will inscribe a circle on the surface of sphere A. The total number of steradians comprising the surface of sphere A is $\Omega_t = 4\pi r^2/r^2 = 4\pi$ sterad. The area A, subtended on the surface of the sphere A by sphere B, may be computed from the following expression:

$$A = \int_0^{2\pi} \int_0^{\theta} r^2 \sin\theta \, d\theta \, d\phi$$

where θ and ϕ are polar coordinates defined as shown in Fig. C.02. Integrating first with respect to ϕ,

$$A = 2\pi r^2 \int_0^{\theta} \sin\theta \, d\theta$$

Then with respect to θ,

$$A = 2\pi r^2 \left[-\cos\theta\right]_0^{\theta}$$

$$A = 2\pi r^2 \left[1 - \cos\theta\right]$$

Thus

$$\Omega = \frac{A}{r^2} = 2\pi \left[1 - \cos\theta\right], \text{ for the case indicated.}$$

Note that the same expression is derived regardless of the value of r; therefore, Ω is the surface area subtended on a unit sphere $(r = 1)$.

C.02 SOLID ANGLE FRACTION

For various practical reasons, in radiation shielding a different measure of the field of view occupied by any object or plane is used. The solid angle fraction is defined as follows:

$$\omega = \frac{A}{2\pi r^2}$$

Therefore, the solid angle fraction subtended by the sphere B on the sphere A is

$$\omega = 1 - \cos \theta$$

The solid angle fraction subtended by a plane rectangular surface which is so located in space that a perpendicular through its centroid passes through the center of a sphere of unit radius (see Fig. C.03) may be computed by the following expression:

$$\omega = \frac{2}{\pi} \tan^{-1}\left[\frac{e}{n\sqrt{n^2 + e^2 + 1}}\right]$$

where $e = \dfrac{W}{L}$ = eccentricity ratio

$n = \dfrac{2Z}{L}$ = normality ratio

W = short dimension

L = long dimension

Z = perpendicular distance from plane of interest to center of "unit" sphere

See Chap. VII, Art. 41, p. 68, Ref. 6.01.

A chart for the solution of the above equation is presented in Ref. 6.02.
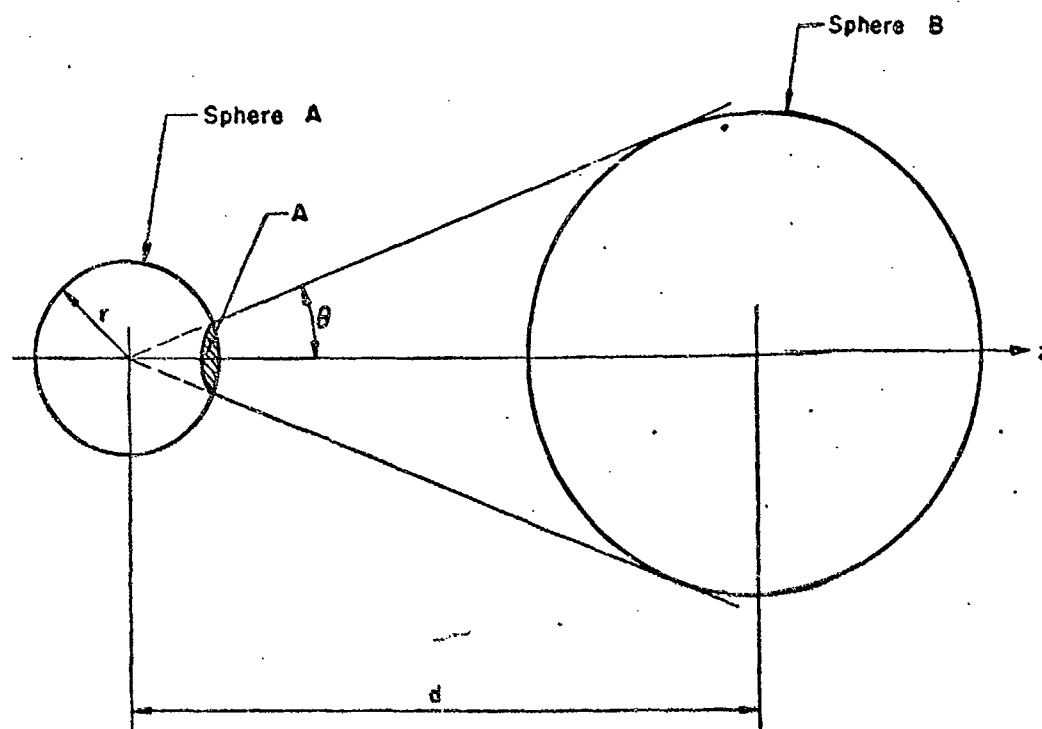
FIG. C.01 SOLID ANGLE FORMULATION

$$dA = r^2 \sin\theta \, d\theta \, d\phi$$
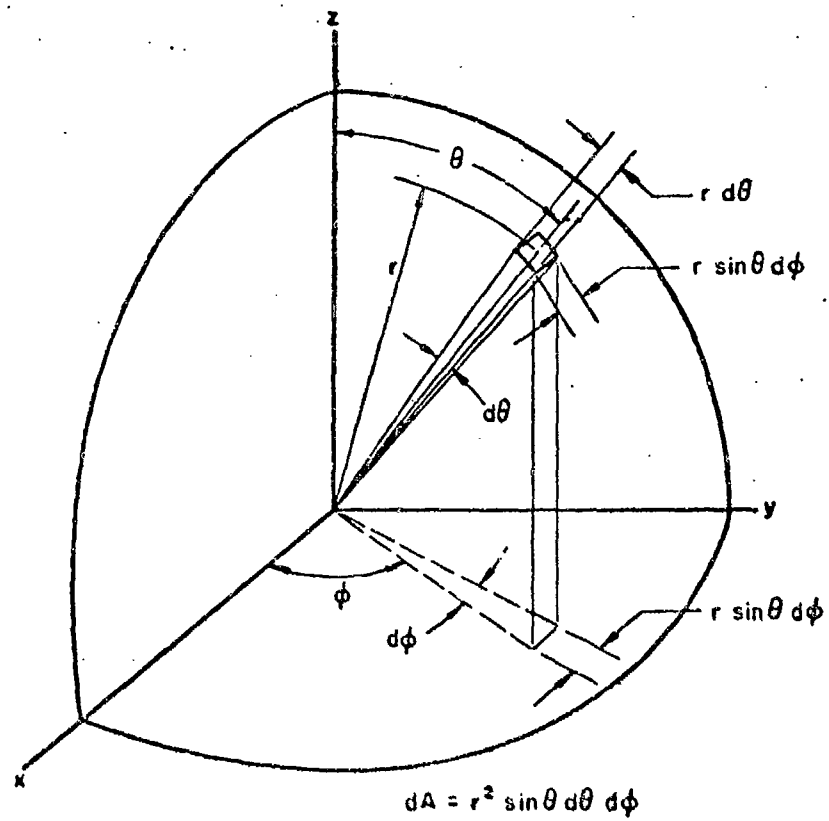
FIG. C.02   CALCULATION OF SURFACE AREA USING

POLAR COORDINATES

.S = WL

Where;

W = Short Dimension.
L = Long Dimension.
Z = Perpendicular Distance
    From Plane Of Interest
    To Center Of "Unit" Sphere.

Z
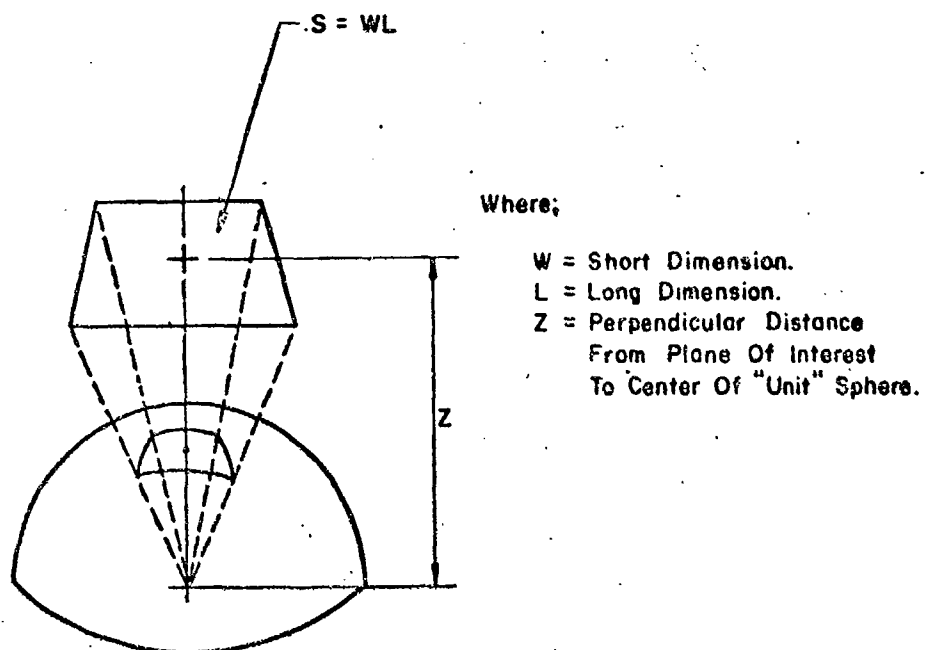
FIG. C.03   SOLID ANGLE FRACTION SUBTENDED BY A PLANE

RECTANGULAR SURFACE

APPENDIX D

POSSIBLE RADIATION HAZARD RELATED TO THE USE OF ALUMINUM BLAST DOOR IN SHELTER ENTRANCEWAY

A. B. Chilton

D.01 INTRODUCTION

There is a possibility of using an aluminum blast door for a nuclear shelter, presumably at the end of the corridor which comprises the entranceway and leads into the shelter space proper. The question exists as to the effect of such a door from the radiation point of view, since it is conceivable that the interaction of the neutron radiation with the door may under certain circumstances create more of a radiation hazard than would exist without the door.

It is difficult to give a precisely accurate quantitative analysis of the situation because: (1) it will depend somewhat upon a precisely defined configuration of the structural elements and a detailed specification of the materials of construction for all elements; (2) the precise distribution of neutron energy and direction at each point in the system is most difficult to obtain analytically, if not practically impossible. However, it is believed that by making reasonable assumptions and some simplifying idealizations in the situation, a definite answer to the basic question can be correctly obtained.

It is assumed that the shelter consists of an entranceway corridor, consisting of two or more legs, leading into a shelter of several hundred persons capacity through a doorway of dimensions about 3.5' x 7'. At this doorway is located a blast door which may consist of an aluminum slab with thickness on the order of an inch, with possibly some sort of strengthening framework (whose effect can largely be ignored from the radiation point of view). Two idealizations of the situation should be considered, as illustrated in Figs. D.01 and D.02. These represent two extremes from the radiation point of view, in that Fig. D.01 represents cases in which the bulk of the radiation may be considered penetrating the door in a direction approximately normal to it; whereas Fig. D.02 represents cases in which the largest component

of the radiation may be considered penetrating the door with a rather extreme slant angle of incidence.

It can be seen that both of the cases assume that radiation passes down the entrance passageway in a somewhat collimated beam along the passageway. This is believed to be a reasonable assumption, although no experimental data on neutrons are known which have demonst ated this conclusively.

Also it will be seen that no knowledge is required of the neutron field, either outside the shelter or within the entranceway. All that is necessary to assume is that the neutron flux is sufficient to provide a possible hazard in the shelter. The analysis will be concerned with the problem: given an arbitrary flux of neutrons incident on the doorway, would the hazard inside the shelter be decreased or increased by the presence (as contrasted with the absence) of an aluminum slab door? In case the hazard is increased, the question will also be discussed as to whether an aluminum door is any worse than a steel door in such respect.

D.02 THERMAL NEUTRONS NORMALLY INCIDENT

1) Interaction Probabilities. The microscopic cross-sections for thermal neutrons on aluminum are taken to be (Refs. D.01 and D.02):

$$\sigma_a = 0.215 \text{ barns } (1 \text{ barn} = 10^{-24} \text{ cm}^2)$$

$$\sigma_s = 1.4 \text{ barns}$$

$$\sigma_t = 1.615 \text{ barns}$$

One obtains the macroscopic cross-sections by multiplying the above values by N, the number of atoms per cubic centimeter, where

$$N = \frac{6.024 \times 10^{23} \text{ atoms}}{27 \text{ gm.}} \times \frac{2.7 \text{ gm.}}{\text{cm}^3}$$

$$= 6.024 \times 10^{22} \text{ atoms/cm}^3$$

Thus,

$$\Sigma_a = 1.295 \times 10^{-2} \text{ cm}^{-1}$$

$$\Sigma_s = 8.43 \times 10^{-2} \text{ cm}^{-1}$$

$$\Sigma_t = 9.73 \times 10^{-2} \text{ cm}^{-1}$$

Assume 1 neutron/cm^2 incident normally upon the aluminum door of thickness T, where T is of the order of 1 inch or less. It is to be noted that the mean-free-path of a thermal neutron in aluminum, the reciprocal of Σ_t, is 10.3 cm. Thus T is much less than a mean-free-path; and one may consider that the probability of two or more collisions in the aluminum is negligible. Hence, the single collision calculation is approximately valid. One finds then that:

1. the number of thermal neutrons/cm^2 absorbed is $1.295 \times 10^{-2} \times T$;

2. the number of thermal neutrons/cm^2 scattered is $8.43 \times 10^{-2} \times T$;

3. the number of thermal neutrons/cm^2 having some sort of

   interaction is $9.73 \times 10^{-2} \times T$.

Note: T is in centimeters.

The effect of small percentages of alloying elements and impurities in the aluminum is considered negligible.

2) Gamma Photons Resulting from Thermal Neutron Absorption by Aluminum. A number of investigators have studied this particular question (Refs. 0.03, 0.04, 0.05), using different techniques. The results they get tend to complement one another, but where they overlap are not entirely consistent. One is left with the problem of making a judgment as to the precise division of energies among the various energy bands of the gamma spectrum. As an aid to this judgment, there is the rule (see Ref. 0.05) that the sum of the products of gamma photon must be approximately equal to the value of the binding energy of the neutron which has been captured. In the case of the Al^{27} (n, gamma) Al^{28} reaction, the binding energy of the neutron is known rather accurately to be (Ref. 0.03) 7.724 MeV. The estimated number of photons in each energy band is given in Table 0.01.

The tissue absorbed dose caused by these photons resulting on the average from a single thermal neutron capture in aluminum is determined as follows:

$$\text{Dose (rads)} = \sum_E \text{(Energy flux, MeV/cm}^2) \times (1.602 \times 10^{-6} \text{ ergs/MeV})$$

$$\times \text{(Energy mass abs. coef. for tissue, cm}^2\text{/gm)}$$

$$\times (0.01 \text{ gm-rads/erg})$$

$$= 1.602 \times 10^{-8} \sum_E \frac{\text{Energy output, MeV}}{4\pi R^2} \left(_m\mu_{en-tiss.}\right)$$

$$= 0.1275 \times 10^{-8} \left(1/R^2\right) \sum_E \text{(Photon Energy)(Intensity)} \times \left(_m\mu_{en-tiss.}\right),$$

where R is the distance in centimeters from the point of photon emission to the point of dose measurement. The computation of the summation over energy is given in Table D.01.

It is to be noted that the gamma rays appearing from the Al^{27} (n,gamma) Al^{28} reaction are not the only gamma ray hazard. Al^{28} is itself radioactive and decays by emission of a 1.8 MeV gamma ray, with a half-life of 2.3 minutes. This radiation is also included in the calculation given in Table D.01.

It is now readily determined that

$$D(R) = 0.1275 \times 10^{-8} \times 19.62 \times 10^{-2}/R^2$$

$$= 2.50 \times 10^{-10}/R^2$$

3) <u>Calculation of Total Hazard Caused by Thermal Neutrons.</u> It is necessary first to convert neutron flux in neutrons/cm^2 to tissue absorbed dose. Usually it is considered necessary to determine the biological dose in rems, by first determining the physical absorbed dose in rads and then multiplying by the RBE ("relative biological effectiveness") of thermal neutrons. In the problem undertaken here conversion from rads to rems is not considered necessary, since the RBE will be taken as unity for neutrons of all energies as well as for gamma rays. (The use of a higher RBE for

neutrons is customary for peacetime purposes, since a degree of conservatism
is required to cover the uncertainties in the precise biological effects
of neutrons and to cover variations in the relative effects for different
biological symptoms. For emergency wartime conditions, this degree of
conservatism is undesirable; and Ref. D.07 (paragraph 11.88) recommends
that unity be used for overall prompt casualty producing effects.)

Snyder and Neufeld (Ref. D.08) give a conversion factor of
4.0×10^{-10} rads for a normally incident thermal flux of 1 neutron per cm^2.
(See also Ref. D.09)

It is now possible to compute the absorbed dose within the shelter
with little further ado. First, one should consider the _reduction_ in the
hazard from the initial beam, caused by the removal of neutrons from it,
either by scattering or absorption. If the beam is essentially straight,
the reduction in absorbed dose is:

$$- \Delta D_{incident} = 9.73 \times 10^{-2} \, T \times 4.0 \times 10^{-10}$$

$$= 3.89 \times 10^{-11} \, T \text{ rads}$$

Next, one should consider the hazard from the thermal neutrons
which are scattered by the aluminum atoms. It may be assumed that the
scattering is isotropic. For each square centimeter of door area, the
thermal neutron flux resulting from the scattering is, at distance of R
centimeters,

$$F(R) = 8.43 \times 10^{-2} \, T/4\pi R^2 = 0.671 \times 10^{-2} \, T/R^2.$$

The dose in rads at distance R, as a result of these scattered neutrons is:

$$D_s = 0.671 \times 10^{-2} \, T \times 4.0 \times 10^{-10}/R^2$$

$$= 2.68 \times 10^{-12} \, T/R^2$$

If the distance of the point of interest from the door is of the
order of or larger than the larger dimension, say 8' or over, the door
may be approximately considered as a point source of A neutrons/cm^2, where
A is the area of the door in cm^2. Then,

$$D_s(A) = 2.68 \times 10^{-12} \, T \, A/R^2$$

$$= 2.68 \times 10^{-12} \, V/R^2,$$

where V is the door volume in cubic centimeters.

Finally, one should compute the absorbed dose caused by the thermal neutron capture gamma rays. From previously determined data we can see that:

$$D_a = 1.295 \times 10^{-2} \, T \times 2.50 \times 10^{-10}/R^2$$

$$= 3.24 \times 10^{-12} \, T/R$$

Just as in the case of scattered neutrons, at a distance of say 8' or more, we may consider the door as a point source having A neutrons/cm^2 incident on it, and find

$$D_a(A) = 3.24 \times 10^{-12} \, V/R^2$$

A more accurate method of computing the radiation level at small distances from a rectangular source can be used to give correction factors to the above expressions. The following correction factors apply to the equations above for $D_s(R)$ and $D_a(R)$, as determined from Ref. 0.10:

Distance	Corr. Factor
17.5'	.98
8	.92
3.5	.74
1.75	.46
0.8	.19

4) Specific Examples. The situation can be brought home most clearly by a couple of examples.

Example 1. Consider the absorbed dose 8' from the center of the 3 1/2' x 7' x 1" aluminum door in the shelter, as compared to the dose that would occur if no door were present. Assume one thermal neutron per square centimeter incident normally upon the doorway.

The dose level without the door, as previously given, is 400×10^{-12} rads, under such circumstances.

The reduction in dose when the door is present is:

$$- \Delta D_{inc.} = 3.89 \times 10^{-11} \times 2.54 = 98.8 \times 10^{-12} \text{ rads}$$

The additional dose due to scattered thermal neutrons and capture gamma rays is:

$$D_s + D_a = \frac{0.92 \times (2.68 + 3.24) \times 10^{-12} \times 2.54^3 \times 42 \times 84}{(8 \times 30.48)^2}$$

$$= 5.3 \times 10^{-12} \text{ rads}$$

Thus, the dose level with the door present would be $(400 - 99 + 5) \times 10^{-12}$ rads, or 306 rads. This represents a reduction of about 23%.

Example 2. Repeat Example 1, with the distance from the center of the door 0.8'.

The original dose level without the door is the same, 400×10^{-12} rads.

The reduction in dose is the same, 99×10^{-12} rads.

The additional dose due to scattered thermal neutrons and capture gamma rays is

$$D_s + D_a = \frac{0.19 \times (2.68 + 3.24) \times 10^{-12} \times 2.54^3 \times 42 \times 84}{(0.8 \times 30.48)^2}$$

$$= 109 \times 10^{-12} \text{ rads.}$$

Thus, the dose level with the door present would be $(400 - 99 + 109) \times 10^{-12}$ rads, or 410×10^{-12} rads. This represents an increase of about 2.5%.

0.03 FAST NEUTRONS NORMALLY INCIDENT

1) General. For neutron energies above thermal, the capture cross-section leading to gamma emission is very small; and this effect may be ignored. At intermediate energy ranges, the interaction of neutrons with aluminum is almost entirely elastic scattering; and, as has been indicated in the previous section, this can only have the effect of diffusing a collimated beam and thus reducing the radiation level within the beam path beyond the door.

For neutron energies from about 2 MeV up to and well beyond
14 MeV, there is appreciable inelastic scattering of the neutrons, with
the emission of gamma rays representing the difference in energy between
incident and scattered neutrons. This then is a region which should be
analyzed in a fashion similar to that for the thermal neutrons.

The cross-sections within this range are not known very precisely,
especially for inelastic scattering; however, they do not vary widely with
energy. It is reasonable to assume the following values for microscopic
cross-sections (Ref. D.02):

	2.5 MeV	14.0 MeV
$\sigma_{el.}$	2.15 barns	0.7 barns
$\sigma_{in.}$	0.35 barns	0.8 barns
σ_{γ}	2.5 barns	1.65 barns

The neutron absorbing and particle producing reactions have rather low
cross-sections in this range.

The gamma rays resulting from the inelastic scattering may have
energies of 0.85 MeV or higher. For neutron energies high enough, up
to 14 MeV, the gamma rays may have energies up to 5.4 MeV. The residual
neutrons will have energies averaging around 1 MeV; and for sufficiently
high energy incident neutron energy the scattered neutrons will have
energies of 0.5 to 4 MeV (Ref. D.11).

The macroscopic cross-sections corresponding to the above
microscopic cross-sections are

	2.5 MeV	14.0 MeV
$\Sigma_{el.}$	$12.95 \times 10^{-2} \ cm^{-1}$	$4.22 \times 10^{-2} \ cm^{-1}$
$\Sigma_{in.}$	$2.11 \times 10^{-2} \ cm^{-1}$	$4.82 \times 10^{-2} \ cm^{-1}$
Σ_{T}	$15.06 \times 10^{-2} \ cm^{-1}$	$9.94 \times 10^{-2} \ cm^{-1}$

These data are directly usable for obtaining the number of interactions of
neutrons with the door. For example, for a door of thickness T (on the
order of 1 inch or less), with one 14-MeV neutron/cm^2 incident normally on
it,

1. the number of neutrons elastically scattered per cm^2 is
    4.22×10^{-2} T;

2. the number of neutrons inelastically scattered per cm^2 is
    4.82×10^{-2} T;

3. the number of neutrons removed from the original beam per
    cm^2 is 9.94×10^{-2} T.

2) <u>Flux to Dose Conversion for High Energy Neutrons.</u> Snyder and
Neufeld (Ref. D.08 and Ref. D.12, Chapter 2) give the following values
of the tissue absorbed dose in rads for a flux of 1 neutron per cm^2:

E (MeV)	rad per n/cm^2
0.5	2.4×10^{-9}
1.0	3.8
2.5	4.3
5.0	5.8
7.5	7.1
10.0	7.0

One may assume by extrapolation that the value for 14 MeV is also
7.0×10^{-9}.

It might be noted that the absorbed dose per neutron is not
quite so dependent upon the neutron energy as in the case of gamma rays.
A reduction of neution energy by inelastic scattering from, say, 10 MeV
to 1 MeV serves to reduce its tissue dose only by a factor of two.

3) <u>Calculation of the Total Hazard from High Energy Neutrons.</u>

(a) The reduction in dose due to the flux of the incident
beam is readily computed, assuming one neutron per cm^2 incident, and
considering a door T cm. thick.

<u>For 2.5 MeV neutrons:</u>

$$- \Delta D_{inc.} = 15.06 \times 10^{-2} \times T \times 4.3 \times 10^{-9}$$

$$= 64.8 \times 10^{-11} \text{ T.}$$

For 14 MeV Neutrons:

$$- \Delta D_{inc.} = 9.94 \times 10^{-2} \times T \times 7.0 \times 10^{-9}$$

$$= 69.6 \times 10^{-11} \, T.$$

(b) In the lack of information to the contrary, it is usually assumed that inelastic scattering at these energies is isotropic. For the purpose of this paper the assumption is quite adequate. For inelastically scattered neutrons, the hazard for each unit area of the door is as follows.

For 2.5 MeV neutrons:

$$D_{si} = \frac{2.11 \times 10^{-2} \times T \times 3.8 \times 10^{-9}}{4\pi R^2}$$

$$= \frac{0.638 \times 10^{-11} \, T}{R^2}$$

If the point of dose determination is sufficiently far from the door, the door can be considered as a point source, and thus for a door of area A,

$$D_s(A) = \frac{0.638 \times 10^{-11} \, T \, A}{R^2} = \frac{0.638 \times 10^{-11} \, V}{R^2}$$

For 14 MeV neutrons:

$$D_s = \frac{4.82 \times 10^{-2} \times T \times 3.8 \times 10^{-9}}{4\pi R^2}$$

$$= \frac{1.46 \times 10^{-11} \, T}{R^2}$$

and

$$D_s(A) = \frac{1.46 \times 10^{-11} \, V}{R^2}$$

(c) The effect of the gamma rays resulting from inelastically scattered neutrons cannot be described with preciseness because of lack of exact knowledge as to the physical data for this effect, but for the purposes of this paper, one may assume the following.

For 2.5 MeV neutrons: the resulting gamma rays have an average mass energy absorption coefficient of 0.03 cm^{-1}.

For 14 MeV neutrons: the resulting gamma rays have an average mass energy absorption coefficient of 0.02 cm^{-1}.

It will also be assumed that the gamma rays are isotropically emitted.

In similar fashion to the development in Sec. 0.02, one may obtain for the gamma rays the following results.

For 2.5 MeV neutrons:

$$D_g = \frac{0.1275 \times 10^{-8} \times 2.11 \times 10^{-2} \times T \times 1.5 \times 0.03}{R^2}$$

$$= \frac{0.121 \times 10^{-11} T}{R^2}$$

For the total door, we have that

$$D_g(A) = \frac{0.121 \times 10^{-11} V}{R^2}$$

For 14 MeV neutrons:

$$D_g = \frac{0.1275 \times 10^{-8} \times 4.82 \times 10^{-2} \times T \times 13.0 \times 0.02}{R^2}$$

$$= \frac{1.60 \times 10^{-11} T}{R^2}$$

$$D_g(A) = \frac{1.60 \times 10^{-11} V}{R^2}$$

(d) At these energies, a large proportion of the elastic scattering is diffraction scattering and it is conservative to consider that all of it is. The angular distribution can be computed theoretically to give results which, if adjusted to experimental data, will give rather precise information. For these energies, the distribution is strongly peaked in the original neutron direction. For the purposes of this paper it will suffice to determine the limits of a cone about the incident direction, within which the distribution is considered isotropic and outside of which it is considered negligible. The limits of the scattering cone may be taken at a half-angle of $\bar{\theta} = \lambda/2\pi R$, where λ is the wave length of the neutron in centimeters, according to the formula

$$\lambda = 28.6 \times 10^{-13}/(E, \text{ in MeV})^{1/2}$$

R is the radius in centimeters of the nucleus being considered, and can be computed as

$$R = 1.45 \times 10^{-13} \times A^{1/3},$$

where A is the atomic number of the nucleus. For aluminum, A = 27, so that R = 4.35 × 10⁻¹³ cm.

For 2.5 MeV neutrons:

$$\lambda = 28.6 \times 10^{-13}/(2.5)^{1/2}$$

$$= 18.1 \times 10^{-13} \text{ cm.}$$

$$\bar{\theta} = (18.1 \times 10^{-13})/(2\pi \times 4.35 \times 10^{-3})$$

$$= .662 \text{ radians, or } 38^{\circ}$$

The number of steradians in a cone of 38° half-angle is $2\pi (1 - \cos 38^{\circ}) = 1.33$. For elastically scattered neutrons from a unit area of the door the hazard will exist at a detection point, if the scattering unit area is within a 38° cone about the direction from which the neutrons are originally incident. This will amount to:

$$D_{se} = \frac{12.95 \times 10^{-2} \times T \times 4.3 \times 10^{-9}}{1.33 \ R^2}$$

$$= \frac{41.9 \times 10^{-11} \ T}{R^2}$$

For 14 MeV neutrons:

$$\lambda = 28.6 \times 10^{-13}/(14.0)^{1/2}$$

$$= 7.64 \times 10^{-13}$$

$$\bar{\theta} = (7.64 \times 10^{-13})/(2\pi \times 4.35 \times 10^{-13})$$

$$= .280 \text{ radians, or } 16^{\circ}$$

The number of steradians in a cone of 16° half-angle is $2\pi(1 - \cos 16^{\circ}) = 0.243$. If the scattering unit area is within the 16° cone, the hazard will amount to:

$$D_{se} = \frac{4.22 \times 10^{-2} \times T \times 7.0 \times 10^{-9}}{0.243 \ R^2}$$

$$= \frac{122.0 \times 10^{-11} \ T}{R^2}$$

4) **Specific Examples.** Examples similar to those in Sec. D.02 will be worked out. Since the 14 MeV case is more severe than the 2.5 MeV case, the latter will not be specifically examined.

Example 3. Consider the absorbed dose 8 ft. from the center of the 3.5' x 7' x 1" aluminum door, in the shelter, as compared to the dose that would occur if no door were present. Assume one fast neutron (14 MeV) per square centimeter incident normally upon the doorway.

The dose level without the door is, as previously indicated, taken to be 7.0×10^{-9} rads, or 700×10^{-11} rads.

The decrease in dose when the door is present is:

$$- \Delta D_{inc.} = 69.6 \times 10^{-11} \times 2.54 = 177 \times 10^{-11} \text{ rads.}$$

The additional dose due to inelastically scattered neutrons and gamma rays from inelastic collisions is:

$$D_{si} + D_9 = \frac{0.92 \times (1.46 + 1.60) \times 10^{-11} \times 2.54^3 \times 42 \times 84}{(8 \times 30.48)^2}$$

$$= \frac{0.92 \times 3.06 \times 10^{-11} \times 16.36 \times 3528}{243.84^2}$$

$$= 2.73 \times 10^{-11} \text{ rads.}$$

At 8' from the center of the door, the number of square centimeters of the door included in a cone of half-angle 16^0 is readily computed to 13,310 square centimeters. Then the additional dose due to elastically scattered neutrons is:

$$D_{se} = \frac{122.0 \times 10^{-11} \times 2.54 \times 13,310}{(8 \times 30.48)^2}$$

$$= \frac{122.0 \times 10^{-11} \times 33,800}{243.84^2}$$

$$= 69.4 \times 10^{-11} \text{ rads.}$$

Thus, the dose level with the door present would be
$(700 - 177 + 3 + 69) \times 10^{-11}$ rads, or 595 rads. This represents a reduction
of about 14%.

Example 4. Repeat Example 3, with the distance from the center
of the door 0.8'.

The original dose level without the door is the same, 700×10^{-11}
rads.

The reduction in dose is the same, 177 rads.

The additional dose due to inelastically scattered neutrons and
gamma rays from inelastic scattering is:

$$D_{si} + D_a = \frac{0.19 \times (1.46 + 1.60) \times 10^{-11} \times 2.54^3 \times 42 \times 84}{(0.8 \times 30.48)^2}$$

$$= 56.4 \times 10^{-11} \text{ rads.}$$

At 0.8' from the center of the door, the number of square centi-
meters of the door included in a cone of half-angle 16° is readily computed
to be 153.7 square centimeters. Then the additional dose due to elastically
scattered neutrons is:

$$D_{se} = \frac{122 \times 10^{-11} \times 2.54 \times 153.7}{(0.8 \times 30.48)^2}$$

$$= 80.1 \times 10^{-11} \text{ rads.}$$

Thus, the dose level with the door present would be
$(700 - 177 + 56 + 80) \times 10^{-11}$, or 659×10^{-11} rads. This represents a
decrease of 6%.

It is to be noted that all reductions and increases are propor-
tional to door thickness, within the limits of the assumptions stated.
Thus, precise answers will depend on door thickness, but the general trends
will not be changed.

D.04 NEUTRONS WITH SLANT INCIDENCE

When the case represented by fig. D.03 is considered, the problem
becomes more complex, and meaningful quantitative results are still more
difficult to come by. The analysis must therefore be a little more approximate

than previously; and results given should not be considered exact, even though given to three or more significant figures.

For the situation shown, there is little likelihood that the beam in the direction of the strongest component of the radiation will enter the shelter, since the radiation will be incident at such an acute angle to the plane of the door that the thickness of the wall between the shelter and its entranceway will probably cut it off. Under such a circumstance, it is clear that the door will be, from the radiation point of view, a hazard rather than a help, since it will tend to become a source of gamma rays and inelastically scattered neutrons and will direct radiation into the shelter while in itself having negligible shielding characteristics.

The extent of this hazard can be computed by comparison with previous results for the normal incidence case. If one assumes a flux of 1 neutron per square centimeter measured in a plane perpendicular to the direction of the flux, then the door will be struck by $A \cos \theta$ neutrons.

The thickness of the door in the direction of the slant flux will be $T/\cos \theta$. In the development of the formulas for neutron inelastic scattering and gamma contributions, these two terms multiply, so that the dependence on angle vanishes (within the limitations of approximation inherent in the formulas). Thus the formulas turn out to be the same as those derived in the preceding sections for inelastic scattering and gamma ray contributions, and these formulas may be used for total flux for all incidence directions which are sufficiently acute that predominately forward (elastic) scattering is excluded.

However, it must be pointed out that <u>any</u> material used in the door of this order of magnitude of thickness is going to present this same "in-scattering" effect. It is therfore a little unfair to mitigate against the use of aluminum for such a reason. It would be better to compare the aluminum door with doors of other materials providing the same strength, so as to see whether there is any substantial difference from the radiation point of view and the amount of this difference.

It is appropriate therefore to compare th effects of an aluminum door of one inch thickness with that of a steel door of equivalent strength.

Since the yield strengths are approximately the same for the two materials (see Sec. 7.05) the steel door thickness may also be considered to be one inch.

The nuclear characteristics of iron which are needed for computation are as follows (Refs. D.01, D.02, D.11).

For thermal neutrons:

σ_s = 11 barns

$\sigma_{n,\gamma}$ = 2.53 barns

The product of gamma energy emitted per neutron absorbed times the average mass energy absorption coefficient is about 10 MeV x 0.016 cm^2/g, or 16×10^{-2}.

The decay gamma emission is small by comparison.

For 14 MeV neutrons:

$\sigma_{inel.}$ = 1.45 barns

The average energy of residual neutrons after inelastic scattering is 0.75 MeV.

The energy emitted in the form of gamma rays per neutron absorbed is therefore 14-0.75 MeV, or 13.25 MeV.

The average photon energy is several MeV, so that the average mass energy absorption coefficient for gamma rays from inelastic scattering can be taken to be 0.020 cm^{-1}.

The angle for effective elastic scattering is computed to be 12.6°, and may therefore elastically scattered neutrons may be considered to be blocked out in the fashion the undeflected neutrons are.

The formulas for the steel door are the same as those for the aluminum door, and therefore there is no need to propound them in detail. The results of scattering and gamma emission from a 3.5' x 7' x 1" steel door are given in Table D.02, showing a comparison with similar results for the aluminum door. These results indicate a much greater hazard from thermal neutrons for the steel door than from the aluminum door; the hazards from high energy neutrons are rather comparable for the aluminum and the steel doors, although the aluminum door still appears less hazardous.

Sec. B.05

D.05 CONCLUSION

It has been shown that for neutrons normally incident on a shelter doorway, the presence of an aluminum blast door of reasonable thickness will not greatly vary the hazard inside the shelter from that which would result if no door were present.

For a case in which the neutrons are incident at such an angle that the direct beam would not penetrate appreciably into the shelter, the presence of an aluminum door would indeed create a greater radiation field within the shelter. However, the aluminum door would create no greater hazard than a steel door of comparable strength; on the contrary the former would probably create less hazard.

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TABLE D.01

(1)	(2)	(3)	(4)	(5)	(6)
Energy Band (MeV)	Average Energy (MeV)	Intensity, photons/ neutron	Col. (2) x Col. (3)	μ_{m}en-tiss.*	Col. (4) x Col. (5)
> 7	7.7	.35	2.965	.0165	4.44×10^{-2}
5-7	6.0	.19	1.140	.0178	2.03
3-5	4.0	.71	2.840	.0203	5.76
1-3	2.5	.38	.950	.0241	2.29
< 1	.97	.10	.097	.0310	.30
Instantaneous gamma total			7.722		14.82×10^{-2}
Decay gamma	1.80	1.00		.0267	4.80×10^{-2}
Total gamma					19.62×10^{-2}

*This is the mass energy absorption coefficient for tissue, as given in Ref. 0.06.

TABLE 0.02

Incident flux = 1 neutron/cm^2

at large slant incidence

Neutron Energy	Basis for Hazard	Value of dose 8' from center of door	
		1" aluminum	1" steel
Thermal	Scattered	2.4×10^{-12} rads	26.6×10^{-12} rads
	Capture gam.	2.9×10^{-12} rads	39.4×10^{-12} rads
	Total	5.3×10^{-12} rads	66.0×10^{-12} rads
14-MeV	Inelas. scatt.	1.63×10^{-11} rads	3.33×10^{-11} rads
	Gamma from Inel.	1.78×10^{-11} rads	3.07×10^{-11} rads
	Total	3.41×10^{-11} rads	6.40×10^{-11} rads

Note: Since the RBE for all radiations is taken as unity, the rads are equivalent to rems, and may be considered as comparable to biological doses.
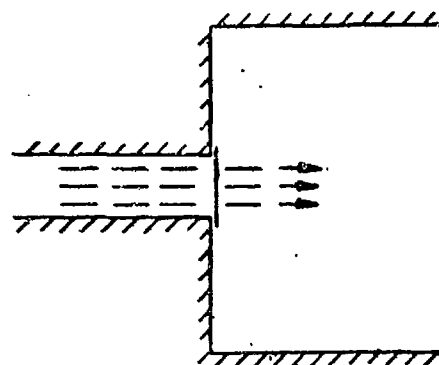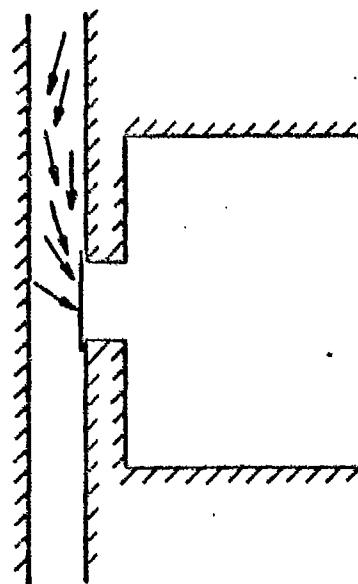
FIG. D.01   NORMAL INCIDENCE

FIG. D.02   PRACTICAL CASE OF SLANT INCIDENCE
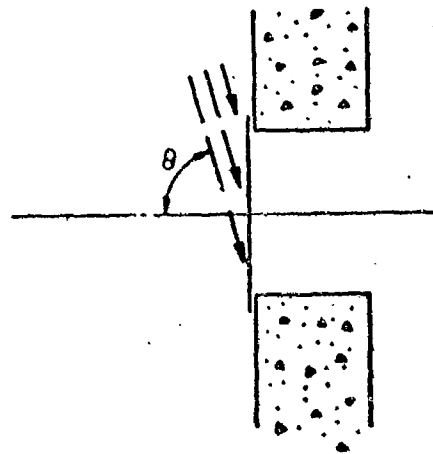
FIG. 0.03 EXTREME SLANT INCIDENCE

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